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VOLUME XIII JANUARY, 1948 NUMBER 1

GEOPHYSICS

A Journal of General and Applied Geophysics

MULTIPLE REFLECTIONS*

T. P. ELLSWORTH†

ABSTRACT

This is the lead paper of a symposium on the subject of multiple reflections. Possible types of multiple reflections are considered and compared with unusual reflections observed on records taken in the Northern Sacramento Valley of California. Geological and geophysical data are presented to demonstrate that a shallow basalt flow is producing identifiable multiple reflections. Consideration is given to the possible frequency of occurrence of multiple reflections in seismic surveys generally and limitations they may place upon seismic interpretations.

MULTIPLE REFLECTIONS

Since the earliest days of reflection shooting geophysicists have been interested in the problem of multiple reflections. You may recall that there were many who sought to prove that reflected waves of sufficient strength to be recorded at the surface could not exist. Then there were some people who suggested that all but the first recorded waves must be multiples produced within the very shallow strata. In fact even today there are theoretical geophysicists who refuse to concede that arrivals beyond a time of the order of one second are sufficiently diagnostic to merit a serious attempt at interpretation. It is fortunate that these thoughts have not had wide acceptance in the oil industry.

Our interest now in the subject of multiple reflections has been stimulated by some most unusual seismograph records recently obtained by many operators in the Northern Sacramento Valley. Independent studies of typical records have resulted in a rather general belief that we have at last found reflections in the ordinary course of operations which must be multiples. The purpose of this symposium is to review for you our studies of this material and that from other

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areas to see if some conclusions may be drawn as to multiple reflections in general. Before reviewing these data it is desirable to consider how multiples may occur, what criteria may be useful in their identification, and then determine whether the reflections on these records fit our specifications.

Perhaps the simplest type and that most likely to occur would be an echo between a strong subsurface reflector and the base of weathering or the ground surface, resembling echoing of the voice between two walls of a room. For convenience this simple multiple reflection will be called Type 1, as illustrated in Figure 1 along with Types 2 and 3 which follow. Going a step further, let us assume a wave which

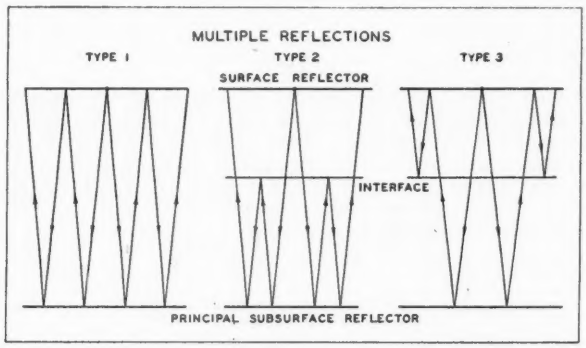

FIG. 1. Simplified diagram of ray paths of common types of multiple reflections.

passes through one reflector, is reflected by a second reflector, echoes between them, and then returns to the surface. This would be an inter-bed echo, as distinguished from the first type which involves but one reflecting bed and the base of weathering or ground surface. This second type could be further complicated by echoing between several beds before reaching the surface. This is our Type 2 multiple reflection.

Returning now to the first type let us introduce an interface, with a low velocity contrast, between a strong subsurface reflector and the base of weathering. When a shot is fired we will record a weak reflection from the new interface, followed by a strong reflection from the original reflector which has a high velocity contrast, which in turn will be followed by echoes between the strong reflector and the base of weathering. But since each echo from the base of weathering acts as another shot, should we not expect that this energy would also be partially reflected from our new interface, causing it to reproduce itself at intervals on down the record along with the primary reflector? I have shown this as our Type 3 multiple reflection.

With a series of many reflecting horizons it is easy to imagine many

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possible combinations of paths which would eventually return some energy to the surface. It is conceivable that several of these arriving together in proper phase would produce a reflection of sufficient amplitude to be seen on a record. The three types mentioned are considered basic but not all-inclusive and a further reason for their selection is that they have been observed, although the writer has no good examples of Type 2. In addition to these, mention should be made of the possibility of multiply-reflected refractions, which certainly could occur, although I have never seen any definitely identified as such.

Among the other authors' prepared discussions to follow, that by John Sloat covers in considerable detail the geometrical relationships which determine the comparative times and moveouts of simple and multiple reflections, their average velocities, normal moveouts, etc. To avoid unnecessary duplication these criteria for identification of the various types of multiple reflections will not be analyzed in detail here but will be pointed out as we look at examples on the records to follow. However, since many of the discussions are related to this one particular area in the Northern Sacramento Valley, and it is unique in many ways, we shall look carefully at those features which set it apart from average shooting country. I say the area is unique because I have made a considerable effort to learn whether multiple reflections have been identified as such elsewhere and to date have had little success. I was told that on one of the Byrd expeditions to Antarctica records were taken which exhibited apparent echoes between the ocean floor and the base of the ice cap. In that relatively simple situation positive identification was readily established. With the publicity being given to this subject now there will no doubt be other examples brought forth, which is a prime reason for presenting this symposium.

The location of this California multiple-reflection area is shown in Figure 2; additional detail is given in Figure 3. A prominent feature in this area is a shallow basalt flow, ranging in depth from 1,500 to 2,000 feet. This map does not attempt to outline its areal extent, as that is not our immediate concern, although from well data and seismograms it can be traced quite readily. Typical thicknesses are given in Table 1 below:

TABLE 1

Richfield Oil Corp.	Hamilton Nord No. 1	167 feet
Richfield Oil Corp.	Dayton Community No. 1	215 feet
Richfield Oil Corp.	Chico No. 1	100 feet
Richfield Oil Corp.	Capital Co. No. 1	50 feet
Standard Oil Co.	Donahoe Fee No. 1	166 feet
Standard Oil Co.	Odell No. 1	110 feet
Superior Oil Co.	Dodge Lands No. 1	120 feet
Superior Oil Co.	Dodge Lands No. 2	100 feet

FIG. 2. Map of California showing area in Northern Sacramento Valley discussed in this paper.

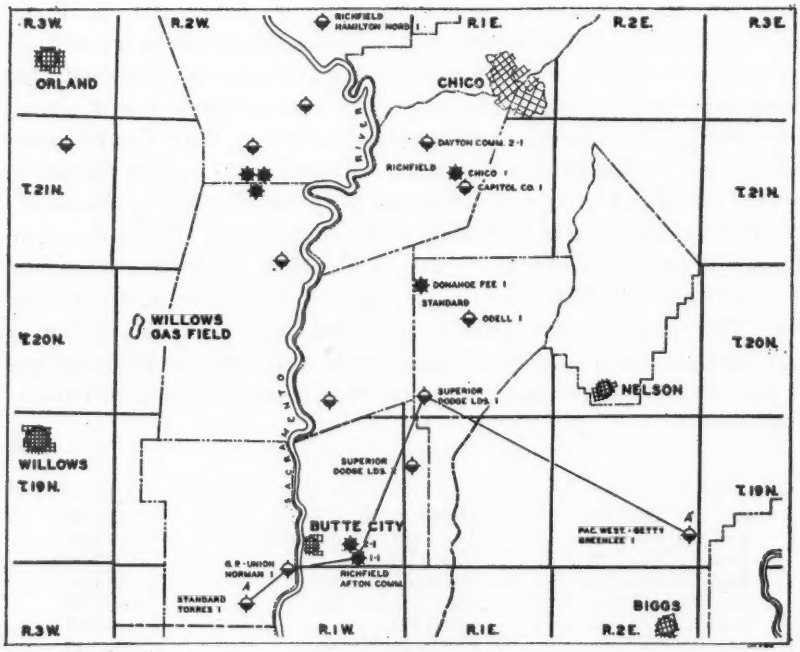

FIG. 3. Detail of area and wells including location of Section A–A′ shown in Figure 5.

In the Richfield-Chico No. 1 well, nine bits were required to drill through 100 feet of basalt. Drilling rates in the various wells ranged from one to two feet per hour in the basalt, and from 30 to 75 feet per hour in the formations above and below the basalt. (Note this for comparison with a velocity survey to follow.) This flow is obviously hard and dense, and exact data on its properties would be of value in our present study, but no cores are available for analysis. However it seems likely that the density of this basalt is in line with values noted in the literature ranging from 2.7 to 3.3 gm/cm³, which are somewhat higher than those for granites, dolomites, and anhydrites, these being among the most dense formations usually encountered.

The results of a velocity survey in the Chico No. 1 well are presented in Figure 4. A velocity of 13,000 plus feet per second was computed for the basalt interval but it was found that this interval also

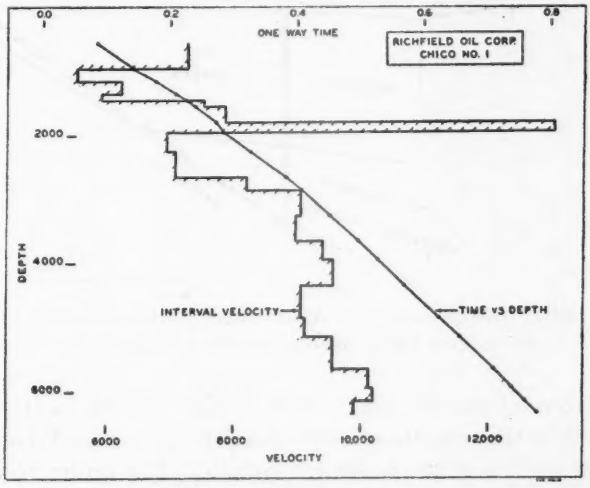

FIG. 4. Plot of velocity data obtained from survey made in Richfield-Chico No. 1 well.

included fifty feet of the lower velocity section below the basalt. The corrected value is closer to 20,000 feet per second but is subject to some error because of the small time differentials and the difficulty in picking the exact top and base of the basalt from the well logs. Recomputed results of other velocity surveys in the area indicate similar high velocities ranging well above 10,000 feet per second.

Section A–A' indicated on Figure 3, running generally from west to east in the eastern half of the Sacramento Valley, is shown in Figure 5. The basalt is seen in the lower part of the Miocene section, just above the unconformity between the Miocene and Eocene beds.

On the log of the Superior-Dodge Lands No. 1 well it can be seen that within the Eocene and the upper Cretaceous there are numerous sands and shales while the lower Cretaceous is principally a shale section. In the next illustration, Figure 6, is shown the relationship of this bedding to reflections on records in the vicinity of the well. The bottom record was shot one and one-half miles east of the well and is typical of records obtained in places where the basalt is absent, or where it does not produce an identifiable reflection. Note the absence of pickable re-

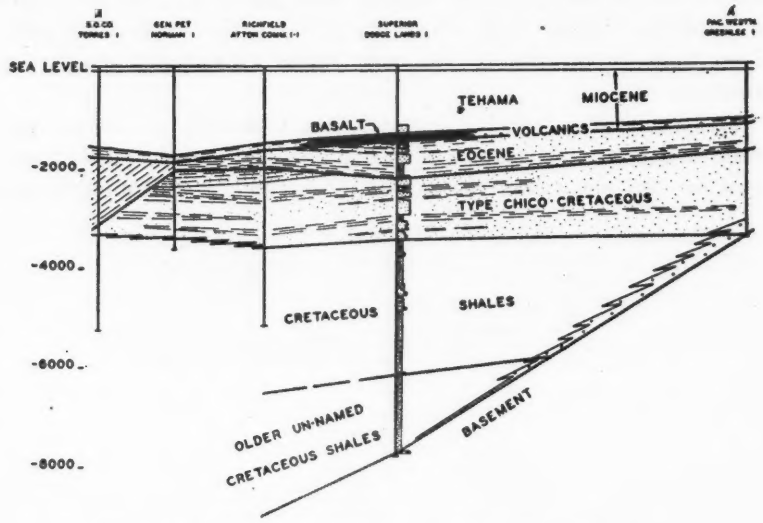

FIG. 5. Geologic section (A–A′) in eastern portion of Northern Sacramento Valley showing position of basalt flow.

flections from within the lower shale section. Based on its depth in several wells in the area, the strong reflection at 1.8 seconds is presumed to be from the top of the basement complex. The center record, shot one mile east of the well, exhibits a definite reflection from the basalt but carries no apparent abnormal reflected energy below it. The top record, shot adjacent to the well, shows a pronounced reflection from the basalt with repetitious impulses continuing out the record far beyond the arrival time of our basement reflection, which can not be found on this record. Certain of these impulses appear at regular intervals as indicated. A fuller discussion of this will follow later. Other records carried out to greater times indicate that these repeating impulses can be recorded with arrival times greater by several fold than that of the reflection from the basement complex. These three records pretty much cover the whole range of normal to abnormal records typical of the area.

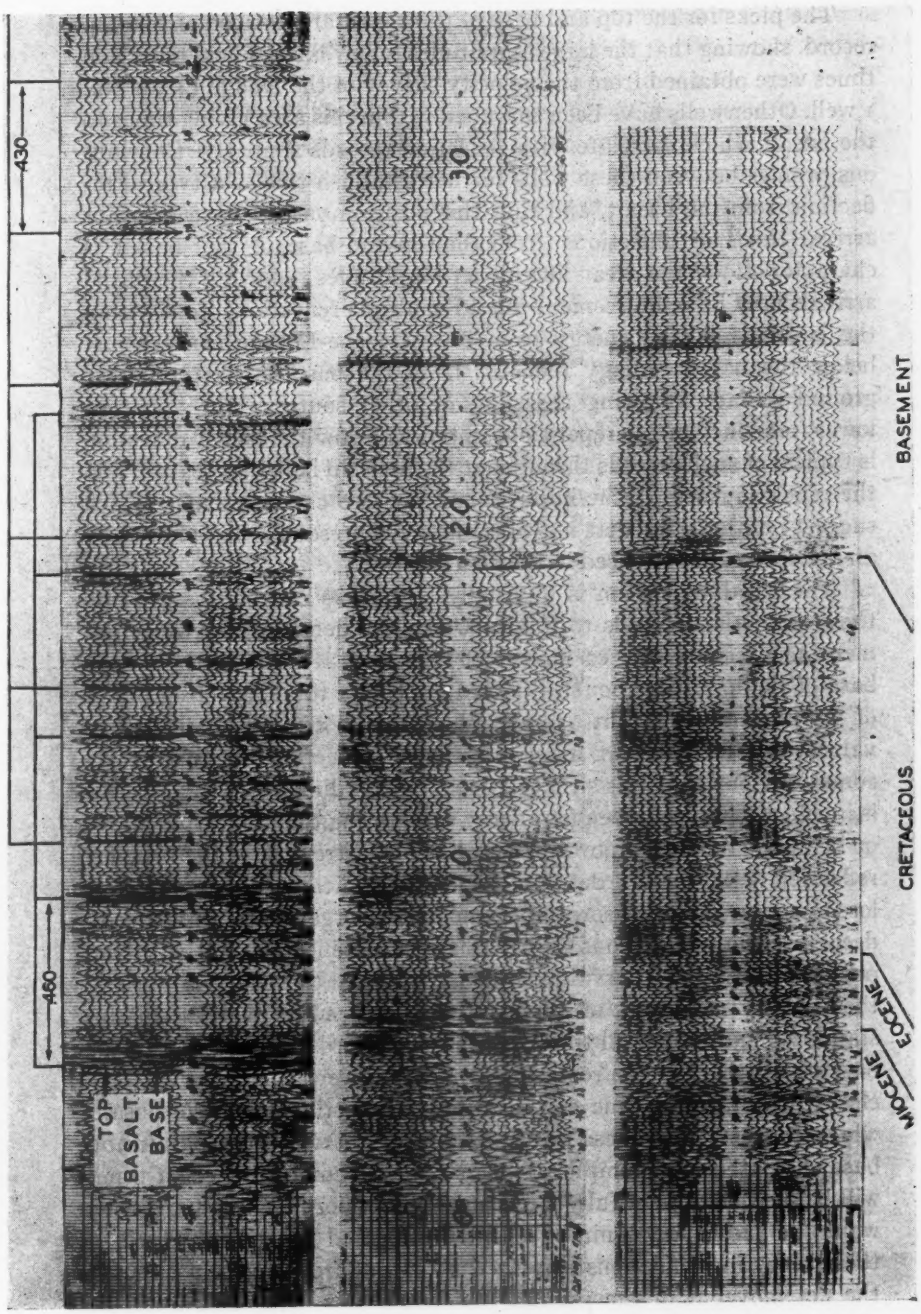

FIG. 6. Typical records in vicinity of Superior-Dodge Lands No. 1 well with geologic time correlations indicated.

The picks for the top and base of the basalt are marked on the top record, showing that the large amplitudes follow later. These reflection times were obtained from the velocity survey of the Dodge Lands No. 1 well. Other wells have been surveyed within this area giving times to the basalt which correlate with reflection records similarly. Continuous profiles between these wells further establish this as a typical reflection from the basalt, and that this position on the wave train for arrival times of reflections from the top and base of the basalt is characteristic of the area. The higher amplitudes following the initial arrivals may be reinforcement due to multiple reflections from within the basalt, reflected energy from the Miocene-Eocene contact just below the basalt, energy reflected from the base of weathering or ground surface following the shot, or other sources. The apparent lower frequency of the repetitious impulses below the basalt reflection is typical of such records throughout the area; in fact that feature and the repetitiousness of the impulses are the two characteristics which suggest on first sight that multiple energy is present, when viewed by an interpreter experienced in the area.

The basalt reflection is unusually strong, as can be observed on these and other records to follow. Using the densities and velocities mentioned earlier, the coefficient of reflection at the top and at the base of the basalt is about 35 percent, giving a total reflecting power of more than 50 percent overall. When this is compared with usual values of a few percent for average good reflecting horizons it becomes obvious that this situation is an extraordinary one. The basalt is in effect a potent screen for energy attempting to pass it from above or below. A further important reason for the strength of the primary reflection is the shallow depth of the basalt, which reduces greatly the loss of energy due to absorption, geometric divergence, etc., relative to deeper reflecting horizons. With this strong reflector, and with impulses repeating at intervals of time about equal to the arrival time of the primary reflection, multiples are strongly suspected. In this instance we find that if all times on this top record are corrected to the base of weathering, the recurring impulses have a time interval very close to the arrival time of the primary reflection from the basalt, which suggests that these are simple echoes between the basalt and base of weathering. Complications involved in computing exact times will be discussed more fully later. Further support for this suggestion would be had by determining that the indicated net dip moveouts of these recurring reflections increased to two-, three-, four-, etc. times the net moveout of the primary reflection, this being characteristic of simple multiple reflections. In this case, however, the primary re-

flection has a net moveout due to dip of zero, thus this multiplication of apparent dip moveout can not be checked here. Examples of this phenomenon will be shown later however.

Continuing now to Figure 7, we have two records each from two profiles recorded on a continuous line with shot-point spacing of 700 feet. These two profiles, being separated by two intermediate profiles, thus are 2,100 feet apart. All of these records were shot at depths close to 40 feet with charges ranging from 2 to 8 pounds. Weathering time intercepts were calculated at 0.007 and 0.008 second, respectively. Each record is a dual recording. The same energy is put through two different amplifier circuits with variable frequency response and recorded separately on the top and bottom half of the record. In the illustration the records overlap each other and are so offset that the primary basalt reflection of the upper record of each pair is opposite the suspected first simple multiple of the basalt reflection on the lower record. The heavy lines across twelve traces are presumed to represent the recurrences of the basalt reflection and the short heavy lines on the upper pair represent intermediate reflections, which also appear to repeat. The times indicated are the intervals between the recurring reflections.

These records were selected for presentation because they demonstrate at once several aspects of our multiple-reflection problem more clearly than usual records observed in the area. They are not typical, because they were carefully chosen, but the points they illustrate can be observed individually on most records from that area. Thus while they are extremely remarkable records in themselves, and in fact are some of the most unusual records I have ever seen, this is principally because they combine in one group of records most of the characteristic features found separately on other records in the general area.

First note that on both pairs of records there has been indicated an interval of time between the primary basalt reflection and its suspected first multiples, and a later equal time interval near the ends of the records. On the upper records the interval of 0.486 second is maintained within limits of a few thousandths of a second throughout the entire record between the marked reflections, whether they be the recurrences of the basalt reflection or those of the two intermediate reflections. This can be checked visually by noting the remarkable lineup of these reflections between the offset records, while observing at the same time the excellent character correlations between the two records even though they are offset by one interval of 0.486 second. On the lower pair of records the time interval between the basalt reflection and succeeding recurrences is 0.477 second as indicated.

While intermediate reflections occur, they are not as clear as on the upper records and were not marked, although repetition can be seen to be present.

The particular point of interest with respect to the latter records is that the reflections as marked are correlated in reverse phase, peak to trough and trough to peak, while on the upper records the correlations are trough to trough and peak to peak. While few people would question the apparent character correlations of the upper records, the question arises as to why the lower records, when offset as shown, are correlated in opposite phase. The reason for this difference in correlation is that the first step in analyzing these records for the existence of multiple reflections requires that we correlate the primary basalt reflection and the repeating reflections following it on the same record. Since we know that the dip on the basalt here is negligible and that we have a flat ground surface and base of weathering, then any simple multiple reflections between these parallel reflectors must occur at approximately equal intervals of time. Thus our correlation of the primary reflection with the first suspected multiple establishes a time interval which must be closely maintained on succeeding correlations on out the record. On the upper records we can correlate the basalt reflection with its indicated multiples, also the intermediate reflections, on a trough-to-trough basis while maintaining equal time intervals. On the lower records we can attempt to correlate similarly trough to trough at intervals of less time or more time than 0.477 seconds with the following results. If we correlate the marked trough of the basalt reflection with the trough immediately preceding the marked peak of the first presumed multiple, we establish a time interval of 0.463 second. When we proceed to correlate at this interval on out the record, we shortly find ourselves well ahead of the principal energy of the reflections we are attempting to correlate, although we will be matching trough to trough so far as they are discernible. On the other hand if we correlate to the trough following the peak marked on the first presumed multiples we then establish a time interval of 0.493 second. Continuing to correlate at this interval we match trough to trough until we find ourselves well past the main part of our reflection when we arrive at the end of our record. In neither case can we correlate satisfactorily between the early and late reflections on the record with these methods. However, if we assume that inversion of phase is taking place and make our correlations from trough to peak to trough as indicated, at the interval of 0.477 second, we find that we maintain a position in the early part of our reflections throughout the length of the record. Further we can observe, through the use of a mirror, that the succeeding reflections correlate very nicely when inverted; also

that alternate reflections correlate satisfactorily in phase, as is apparent from even a casual inspection of the records. This, then, is the reasoning followed by which the visual correlations were made.

At this point the reader would hardly question the existence on these records of repeated reflections but he would be justified in questioning the significance of the time intervals obtained as above. It could be concluded that these intervals represent the two-way travel time between two reflecting interfaces which are producing these apparent echoes, such as, for example, the top of the basalt and the base of the weathered layer. If it were also determined from the records that one-half of this interval time does coincide with the measured time between these reflectors, then it would suggest that we had both proved the existence of multiple reflections on these records and found their source. Unfortunately studies of many records of this type do not demonstrate any consistency in such determinations, although some close fits are obtainable. That this is so should not be surprising when we consider the physical conditions involved in the problem.

As noted earlier the basalt flow ranges in thickness from 50 to 215 feet at the wells drilled in the immediate vicinity, and its top and base provide two roughly parallel reflectors with high coefficients of reflection of possibly 35 percent each. Therefore the basalt reflection noted on our records is at least a dual one and may carry energy from other sources also, as noted earlier. Changes in the thickness of the basalt certainly produce variations in the phase characteristics of the overall wave form observed and it should be recalled that the reflection coefficient at the top of the basalt is positive while that at the base is negative. From this it can be seen that a consistent wave shape would not be expected throughout the area, which fact is borne out by the records in our files.

Consider now the situation pertaining to the possible surface or near-surface reflectors required to produce these apparent multiple reflections. Measured subweathering velocities average about 5,500 feet per second, with velocities in the weathered layer ranging from 1,000 to 1,500 feet per second. Assuming conservative contrasting values for densities, the coefficient of reflection at the base of weathering is in the order of 50 percent. Since this surface is uniformly flat it should be an excellent reflector. It is also very close to the ground surface as shown by the weathering-time values of 0.005 to 0.010 second and its low velocity of 1,000 to 1,500 feet per second. This condition, combined with careful time measurements on certain records, has led some of us to believe that the ground surface also comes into play in producing multiple reflections. I should add that this is suggested particularly where the weathered layer is very thin and

controlled by ground water close to the surface. When the weathering time values are more than 0.010 second the indicated time intervals of the multiples suggest the base of the weathered layer as the principal reflector, if not the only one. In some cases, then, energy reflected upward from the basalt is probably reflected downward again by both the base of the weathered layer and the ground surface, while in others perhaps only the the first of these.

To summarize, there are at least two lower reflectors and one or two upper reflectors which are containing a large part of the energy from the shot and causing it to echo between them. This situation produces the multiple reflections and so complicates the resulting wave forms of the successive reflections observed on the records that it is almost impossible to predict whether the resultant wave should be inverted with each repetition or should repeat in phase. This, I think, explains why they sometimes appear inverted and at other times do not, just as the two pairs of records in Figure 7 demonstrate.

It has been observed that in some instances the simple multiples of the basalt die out and other repeating reflections become more prominent. Various possible reasons for this phenomenon have been advanced but it has not been satisfactorily explained. Contributing factors may be cancellation due to waves arriving simultaneously in opposite phase while other reflections are built up by coincidence of arrivals from several sources. Adequate determination of such effects would require a complete knowledge of the geologic conditions plus closely controlled seismic measurements which could be provided only by a planned experimental program. Preparations were made early in World War II for such a program but shortages of men and equipment forced us to cancel our plans.

So far the discussion of these records has been limited largely to the multiples of the basalt reflection which fall into our earlier classification of simple multiples. The intermediate repetitions marked on the upper pair of records require a different explanation. That they are observed less frequently in this area suggests that the wave paths are more complex and involve more reflecting surfaces. Careful study indicates that they are repeating at the same interval of time as the simple multiples, therefore they appear to be a product of the repetitions of the basalt reflection. Since there are two reflections above the basalt reflection from interfaces between the basalt and the surface, which have the same time separation from the basalt as do the repeating impulses, it is possible to postulate one or more paths which this energy has taken to produce these results. In my opinion the preferable assumption is a travel path from the shot to the basalt, back to the base of weathering or ground surface, down to these two interfaces,

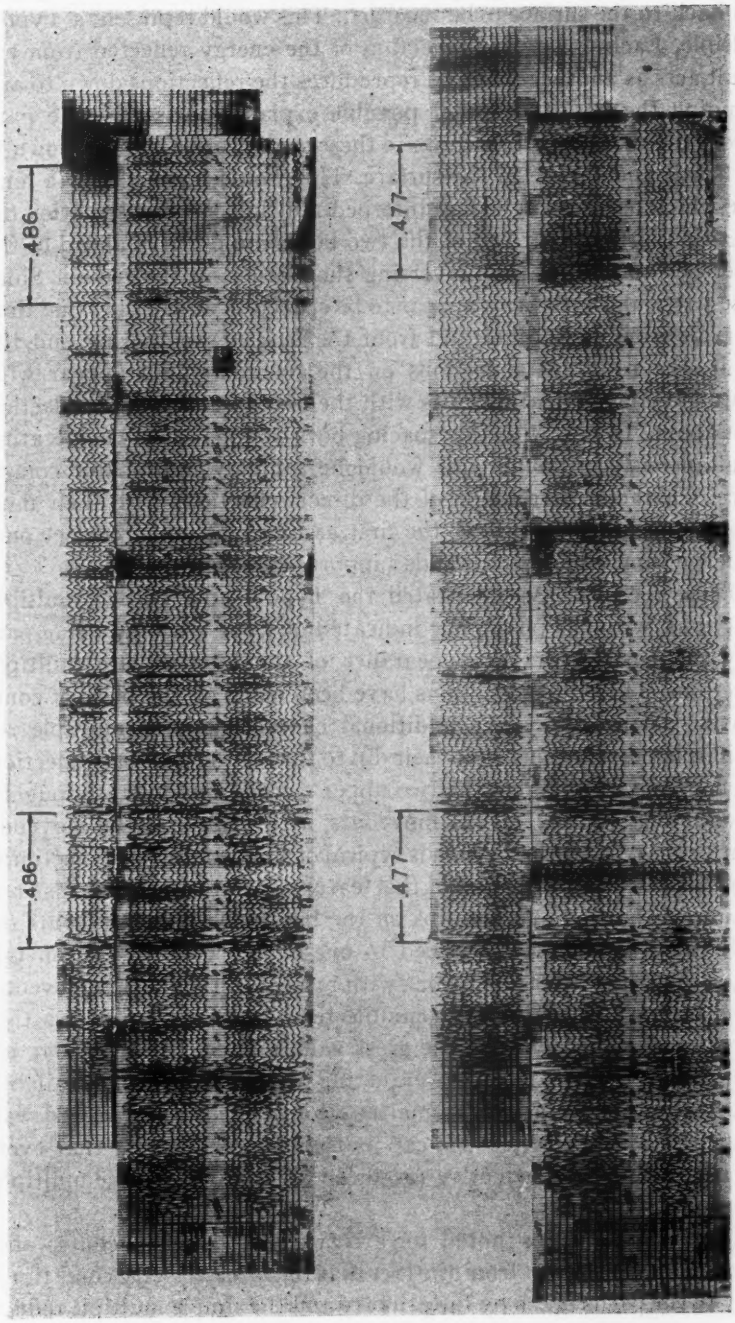

FIG. 7. Records in vicinity of Standard-Odell No. 1 well showing two types of multiple reflections.

and back to the surface to be recorded. This would represent a Type 3 multiple. Each downward reflection of the energy reflected from the basalt acts as another shot and reproduces the reflections down to and including the basalt. Another possible explanation is that the path is from the shot to the basalt, up to these shallower beds, back down to the basalt and thence to the surface. This would be our Type 2 multiple which has been called an interbed multiple. In this situation the repetition of the lower bed of the two beds would arrive ahead of the upper bed reflection, thus reversing their order on the record. Since these particular interfaces appear to be spaced at about the same time intervals from each other and from the base of weathering and the basalt, the resultant reflections on the records would appear with about the same arrival times as with the first assumption of reflection from above. In fact with this spacing both actions could be operating simultaneously, although this would be a highly improbable coincidence. Character correlation of the direct reflections with their multiples strongly suggests that the first assumption is the correct one. Evidence from other records adds support to this hypothesis.

These records have illustrated the Type 1 and Type 3 multiple reflections, with the possibility indicated of Type 2 energy being partially responsible for the appearance of the intermediate multiple reflections. These identifications have been made on the basis of comparative arrival times. An additional characteristic of multiple reflections is the relationship of their dip to that of the primary reflection or reflections. In Figure 8 the two upper records demonstrate roughly the doubling, tripling, etc. of moveouts, with respect to the moveout of the primary reflection, which is typical of simple multiple reflections. There are few good examples of this feature on our records in this area because of the usual gentle dips on the basalt. Normal moveouts on single-ended spreads are reduced to one-half, one-third, etc. on the first, second, and later repetitions with respect to the normal moveout of the primary reflection. The middle record of Figure 8 shows this approximate reduction with the gross values noted. Our files have no examples on which adequate weathering and dip control is available to correct to net values of normal moveout. The bottom record was shot with an ordinary electric cap as the charge, showing that even that small amount of explosive produced at least two visible multiple reflections.

These simple ratios noted for arrival times, dip moveouts, and normal moveouts result from the fact that the same velocity conditions apply to the paths taken by the primary and the simple multiple reflections, therefore average velocity measurements afford another approach to the problem of identifying multiple reflections. In fact, ve-

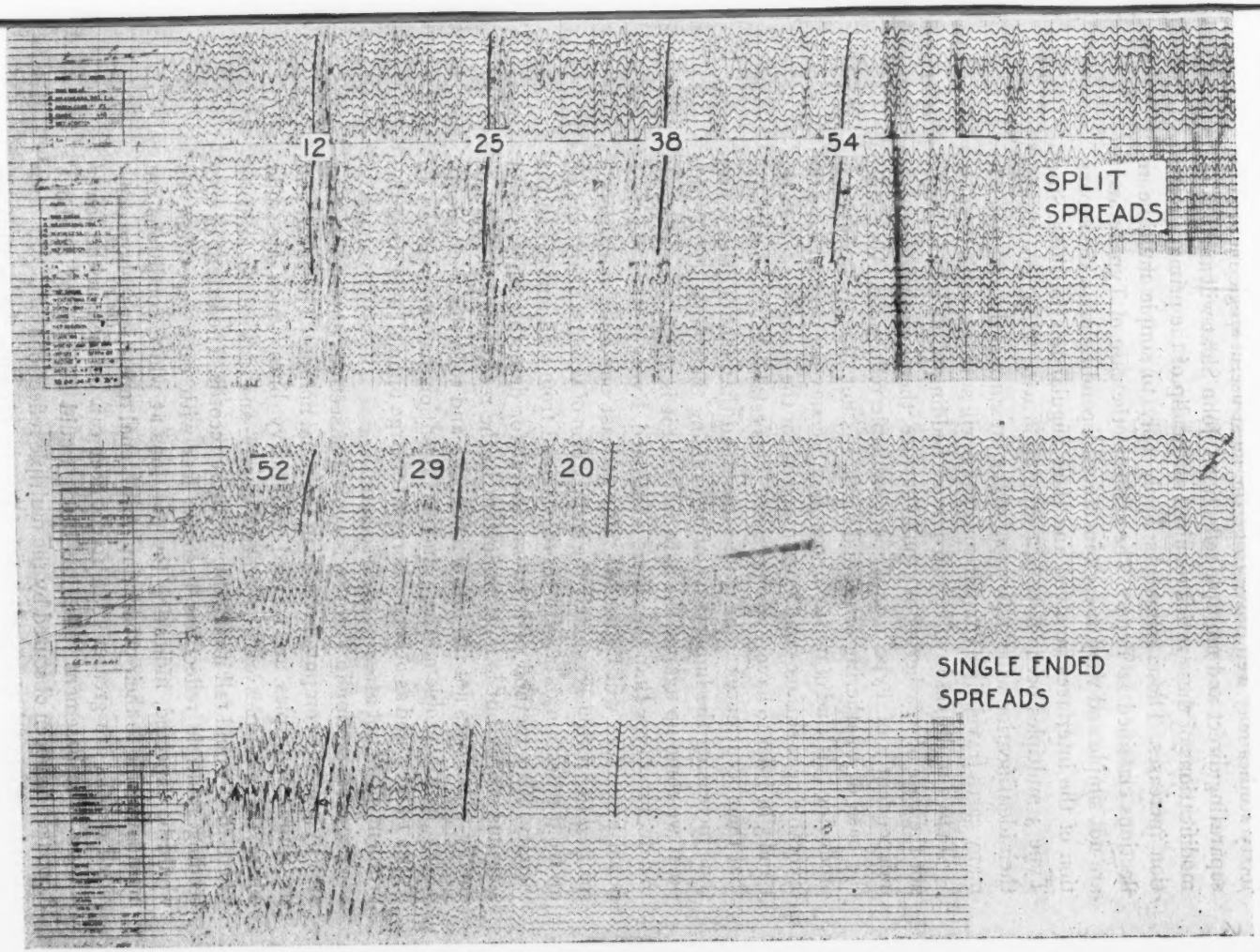

FIG. 8. Top two records' moveouts (in milliseconds) are combined to show increase of dip moveout with each repetition of the basalt reflection. Center record illustrates gross moveout values on basalt reflection and multiples on single-ended spread. Bottom record shot with cap and without automatic volume control.

locity studies may well prove to be the most useful single method for separating direct and multiple reflections. John Sloat will analyze the modifications of these ratios required as the dip of the primary reflection increases. These comments apply only to simple multiple reflections classified as Type 1. The ratios in the case of Types 2 and 3 are not simple and vary in each instance, depending upon the separation of the interfaces involved and their angular relationships. Since Type 3 multiples occur only in conjunction with Type 1 multiples, their identification will follow proof of the presence of the first type. In many cases travel-time comparisons alone will suffice for this purpose.

Type 2 multiples involve two or more bedding-plane interfaces and not the base of weathering or ground surface, therefore they can occur independently of Type 1 or Type 3 multiple reflections. Also, since the base of weathering or ground surface is not directly involved in producing this kind of multiple reflection, we may not need to have the favorable near-surface conditions required for the occurrence of Types 1 and 3 in order to have Type 2 present. This establishes the possibility that their occurrence can be more widespread than that of other kinds, thus increasing the importance of recognizing their presence. At this point we come up against the hard fact that it is much more difficult to detect this type than the others mentioned. Every method of attack noted heretofore will be needed, plus at least one more not directly referred to previously, namely the comparison of velocity charts drawn up from reflection data with those obtained from well surveys in the vicinity. This method of is course useful for detecting any kind of spurious energy but is most important in the recognition of multiple energy which does not fall into our Types 1 and 3. In this Sacramento Valley basalt problem, the principal attention has been given to Types 1 and 3, and as other authors will enlarge upon all aspects of this problem, I will not attempt to do so here.

The cross section in Figure 9 is typical of sections obtained in that area by plotting computed results in the usual manner. The basalt and its simple multiples are marked with heavy lines which are solid where the multiples can be picked clearly and dashed to indicate where they would fall if pickable on those records. The extent of succeeding multiple reflections becomes less with each repetition, as would be expected, indicating the positions at which conditions are most favorable to their production. Additional repetitions whose computed depths are greater than 10,000 feet can be seen in the lower margin. The basement reflection which would be expected at about 8,000 feet has been obscured by the multiple reflections.

This concludes the material I have to present. To summarize briefly, three types of multiple reflections have been considered, with-

out ruling out other possible types, of course, and examples of two of these have been seen on records from the Sacramento Valley. Because other papers will deal with this same area, a review of geologic conditions was introduced. It can readily be seen that certain unique circumstances prevail here, especially with regard to the reflecting properties of the basalt sheet, the base of weathering, and the ground

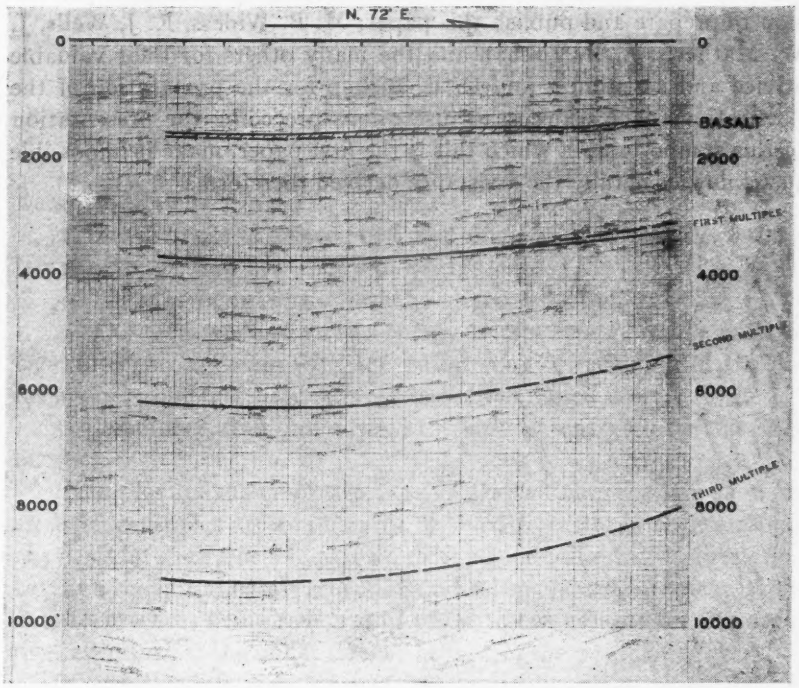

FIG. 9. Typical cross section obtained with usual computing methods showing position of the basalt and its multiples. Some reflections plot in lower margin at twice the known depth to basement.

surface. The existence of multiple reflections has also been associated with a very thin weathering zone controlled by a water table close to the surface. One would be tempted to conclude from the unusual combination of circumstances present in this area, and the failure to date to observe multiple reflections in other areas, with only minor exceptions, that they are seldom a problem. However, although our Types 1 and 3 are rather easily identified and apparently are seldom seen, I would be concerned that Type 2 multiple reflections may be more prevalent than first suspected and that their lack of recognition as such, may be due in part to the greater difficulty in positively iden-

tifying them. Certainly this aspect of the problem is worthy of close and continued study even though the multiple-reflection question as a whole does not seem to present a serious limitation to seismograph interpretation except in isolated cases.

ACKNOWLEDGMENTS

The writer wishes to thank Richfield Oil Corporation for permission to prepare and publish this paper; M. B. Widess, R. J. Wells, J. W. Mathews, F. B. Tolman and the many others for their valuable advice and assistance; and C. E. Bishop for the preparation of the illustrations. The widespread discussions preceding the presentation of this symposium, of which this is the first paper, make it impossible to acknowledge fully the assistance derived thereform.

REMARKS REGARDING MULTIPLE REFLECTIONS*

CURTIS H. JOHNSON†

These comments and illustrations are designed to show that in Butte County, California, at least, multiple reflections *do* exist. When to suspect them and how to evaluate the probability of their existence is discussed in the light of examples from this area.

The following factors should arouse the suspicion that multiple reflections may be present:

1. The presence of a sharp velocity contrast at the base of the weathered layer.
2. The presence of a cored bed of high velocity or density contrast (such as the shallow basalt flow in Butte County).
3. The presence of an abnormally strong reflection.
4. The recurrence of strong energy bursts at apparently uniform time intervals agreeing with the initial time of reflection of the abnormally strong reflection referred to the weathered layer.
5. Sometimes, but not always, a lack of energy between such bursts.

Examples are shown of two cases in Butte County where as many as seven multiples are confidently believed to exist. In each example one basis for such a belief is shown to be a good wave-shape correlation between the initial basalt reflection and subsequent recurrences, alternate recurrences being reversed in phase to compensate for the negative reflections at the under side of the base of the weathered layer.

In one example the times of recurrence have been picked very carefully and the recurrence interval is shown to be constant within the customary limits of error in seismograph work, and to agree with the initial reflection time to the basalt within the limits of error of the weathering correction. The basalt reflection in its first six appearances is plotted on a time section over three continuous split profiles and shows with great clarity the increase in apparent time-dip with increase in the multiple number.

This same example illustrates the presence of reflections from beds above the basalt multiply reflected in the basalt and suggests that in places, the entire seismogram, including the spaces between multiples of the basalt reflection, may consist of nothing but multiple reflections of the bed sequence above and including the basalt.

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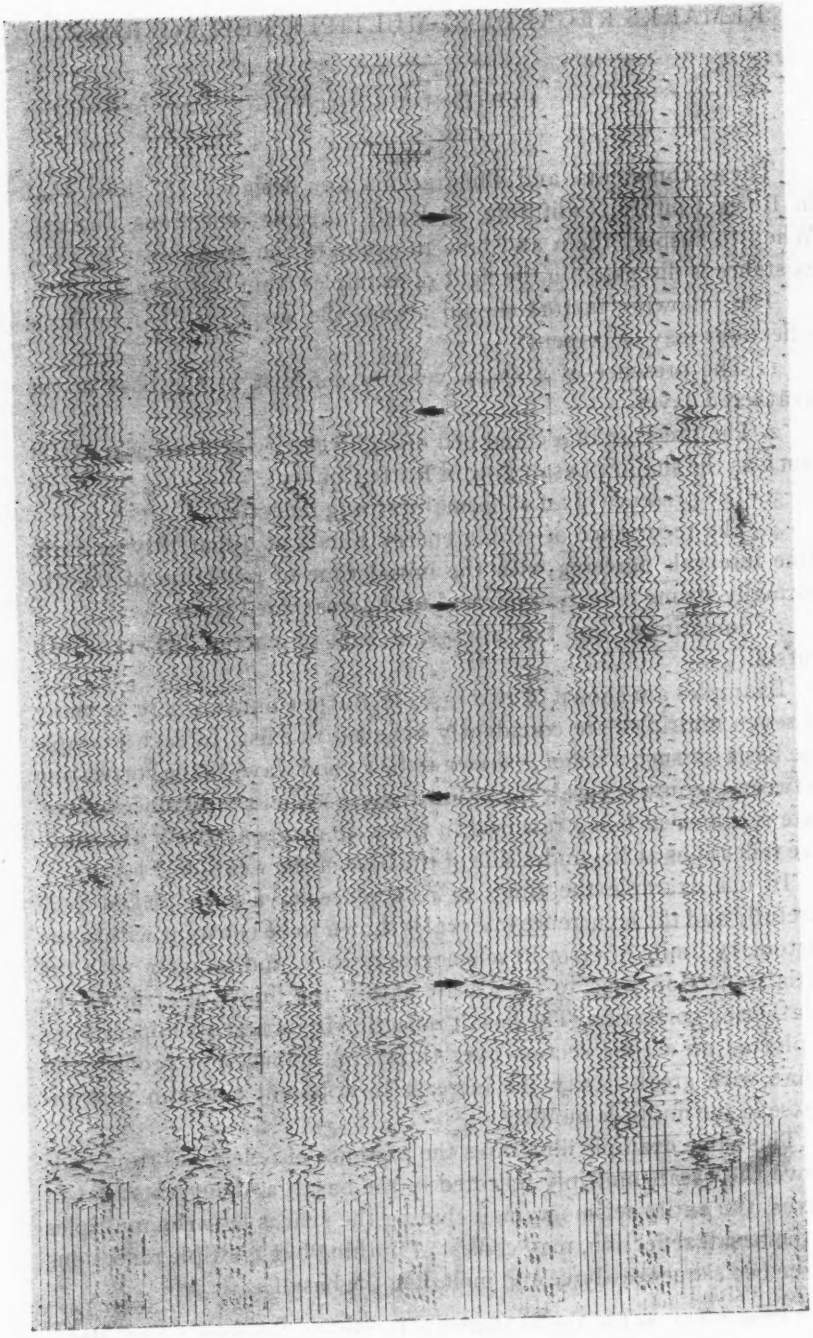

FIG. 1. Multiple reflections between weathered layer and top of basalt.

Referring now to the figures in detail, a group of seismograms from six adjacent continuous profiles are shown in Figure 1. The black arrows designate the deep trough of the basalt reflection and its subsequent recurrences as alternate peaks and troughs in the first four multiples. The type of record immediately adjacent to the arrows suggests the presence of multiples by the most casual visual inspection. Records like the top one, however, are not so easily interpreted, but even here, a casual inspection reveals a suspected double reflection. More records similar to this top one are shown in Figure 4 and are evaluated in Figures 5 and 6.

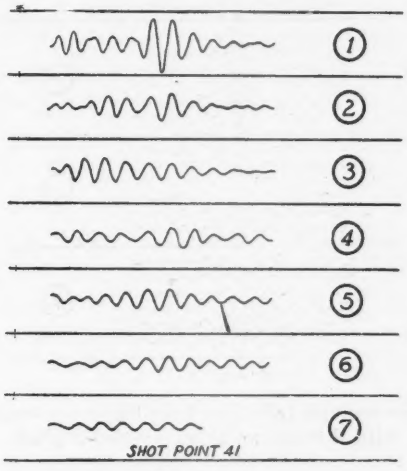

FIG. 2. Successive multiple reflections from Figure 1 recorded on same trace, with alternate multiples reversed in phase.

The multiple reflections of Figure 1 on the trace just below the black arrows are shown at a larger scale, alternately reversed in phase, and juxtaposed in Figure 2, where it is seen that, with due allowance for a decrease in amplitude with multiple number, a fair wave-shape correlation is evident.

It is never very easy to recognize wave-shape similarities from single trace records as reproduced in Figure 2, so to give a better idea of the really excellent wave-shape correlation between the basalt reflection (1) and its first three multiples (2), (3), and (4), the sixth to twelfth traces below the black arrows of Figure 1 have been reproduced in Figure 3, each trace having been reversed in phase on (2) and (4) to correct for the phase change due to reflection from the bottom side of the base of the weathered layer.

A more complicated and more insidious example of multiple re-

flections is shown in Figure 4, where unlike the lower seismograms of Figure 1, these records contain many reflections, some outstanding, between the times of multiple recurrence of the basalt reflection. At first sight the records of Figure 4 (and the upper record of Figure 1) might be presumed to be normal, since recurring single bursts of energy do not immediately catch the eye. However, detailed study of the wave shapes and time intervals proves that the basalt reflection

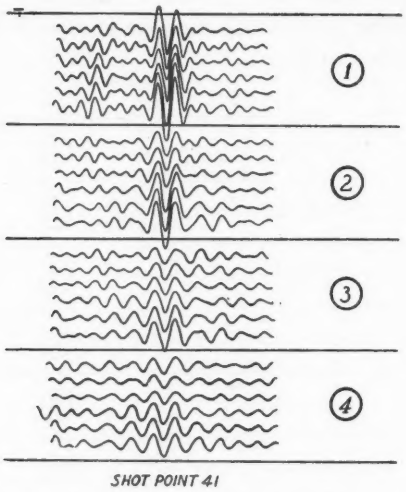

FIG. 3. Successive multiple reflections from Figure 1 recorded on six traces, with alternate multiples reversed in phase.

is just as surely repeated over and over again in Figure 4 as it was in Figure 1. This is shown by the middle open arrow of each group of three placed along the top of Figure 4. In addition, other reflections reappear repeatedly with the same interval, examples being designated by the first and third open arrows of each group along the top of the figure. Once this grouping has been pointed out, the general similarity between the second and third groups strikes the eye quite forcibly on the upper seismogram of Figure 4.

It is, of course, difficult to portray in a single figure, or to convey completely from one person to another, all the factors that go into a judgement of wave-shape correlation, but an attempt has been made along this line in Figure 5. This shows, at a larger scale, selected traces, alternately reversed in phase and juxtaposed, in an effort to portray some of the qualities characterizing a singularly good wave-shape correlation between the various recurrences of the group of three waves indicated by open arrows in Figure 4.

The letters *A*, *B*, and *C* of Figure 5 are the three prominent troughs

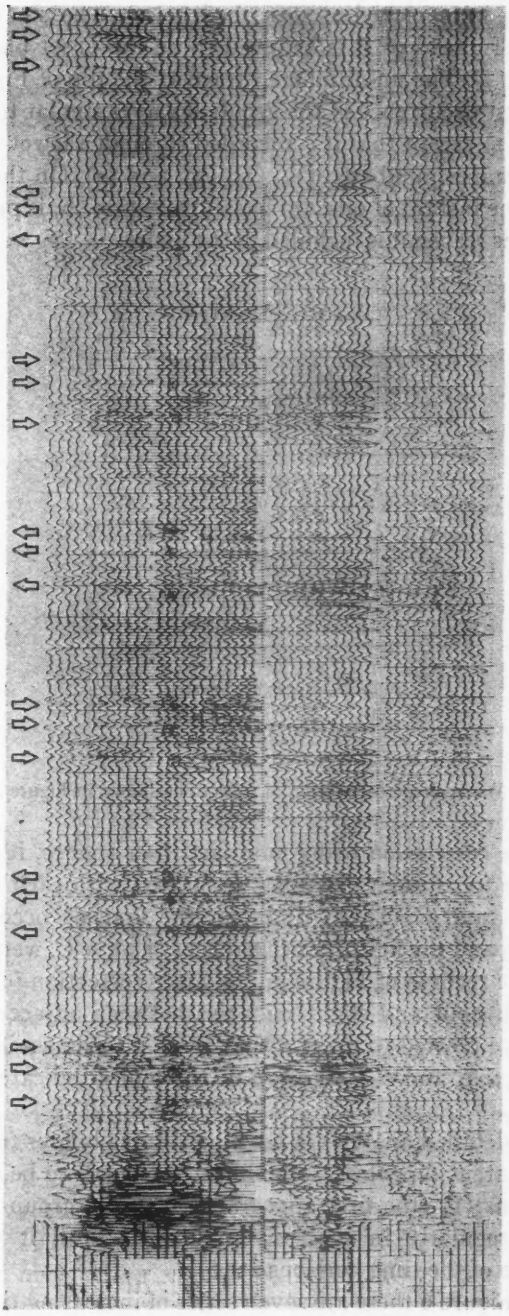

FIG. 4. Records showing three separate reflections multiply reflected as a group.

on which times were picked as described below. The small arrow a "leg" and a half ahead of *B* is believed to be the onset phase of the basalt reflection *B*. The un-numbered trace at the top of Figure 5 is a record of the first occurrence of the group of waves similar to the trace below marked (1) except that it is recorded through a lower-frequency filter than the traces numbered (1), (2), (3), and (4). On this low-frequency trace, the instant of onset of basalt reflection, *B*, is particularly clear and for this reason it is included in the figure.

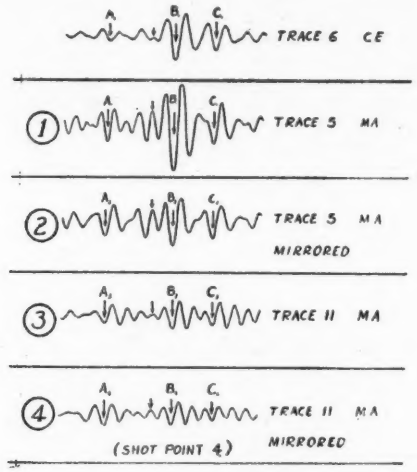

FIG. 5. Wave-shape correlation of reflections shown in Figure 4.

Wave-shape correlation being more art than science, it is perhaps more satisfying to consider the *times* associated with each recurrence of waves *A*, *B*, and *C*. These times for the first six occurrences of waves *A* and *B*, and the first five occurrences of wave *C*, were carefully picked from the records of Figure 5, and after correction for weathering, normal moveout and slight miss-ties between adjacent profiles, these times were plotted to make a time section as shown in Figure 6. The numerals 4, 5, and 6 at the top of the figure indicate the three shot points.

Without a detailed analysis of the times, it is obvious from Figure 6 that the apparent dip,which was almost too small to be recognized in time horizons (1) (the first appearance of wave group *A*, *B*, and *C*), increases regularly in successive multiples until it becomes a striking feature of the time horizons at (6).

As seen in Figure 6 there are seven series of increasing times shown by the circled plotted points at seven locations, those between shot points 4 and 5 and between shot points 5 and 6 being averages of the

tying times from the adjacent profiles. Thus there are 119 times available for statistical study. On the assumption that each numbered group in Figure 6 was a multiple reflection, straight lines were fitted to the time values at all seven locations with the additional proviso that smooth time horizons could be drawn through the time values picked from these straight lines. The deviations of the 119 observed times from these times obtained on this assumption of multiples, plotted as a symmetrical Gaussian error curve with an indicated probable error

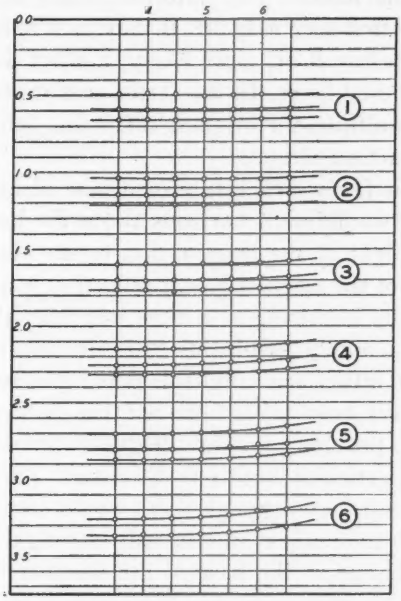

FIG. 6. Time section of events *A*, *B*, and *C* of Figure 5.

of ±0.002 second. This probable error being of the same order of magnitude as errors commonly observed in reflection seismograph work, it becomes highly probable that the observed reflection groups (2) through (6) are indeed multiples of group (1).

At the seven locations of Figure 6, the multiple interval indicated by the slopes of the straight lines described in the preceding paragraph was compared to the time of onset of basalt reflection *B* referred to the base of the weathered layer, and the average deviation was found to be 0.006 second. The probable error in the multiple interval was ±0.002 second; we may assign a probable error of ±0.002 second to the basalt reflection time, and since the weathering data were poor at this location, we may assign a probable error of ±0.002 second to the weathering correction, making a total of ±0.006 second. Thus it is not

unreasonable to believe that we have picked the instant of onset of the basalt reflection and that the multiple reflections take place between the basalt and the base of the weathered layer.

The recurrence of reflections *A* and *C* at the same interval as *B* leaves little doubt that, whatever the cause of their original reflections, all their multiple reflections occur between the basalt and the base of the weathered layer. It seems fairly clear since *A* occurs originally above *B*, that it is originally reflected from a bed a short distance above the basalt. Two interpretations of reflection *C* are possible since it is first seen *below B*. It may be a reflection from a bed a short distance below *B* or, more likely, a short distance below the base of the weathered layer. In the latter case its first recognition is actually its first multiple, the original reflection being lost in the high energy of the refraction arrivals.

In view of this fairly well established case of multiple reflections originating from two different horizons above the basalt, it is perhaps not too great a flight of the imagination to say that *every* reflection beyond the time of the original basalt reflection is a multiple of some reflection originally occurring at a time less than the original basalt reflection. Thus a highly suspicious attitude toward *every* reflection in areas known to return *some* multiple reflections seems justified.

Comments have been made here relative to recognizing multiple reflections and to proving to a high degree of certainty that they are multiple at the particular locations discussed. The same techniques may be applied anywhere, though there would seem to be little point in spending much time unless an unusually strong reflecting bed and a sharp velocity change at the base of the weathered layer were both known to exist in an area.

IDENTIFICATION OF ECHO REFLECTIONS*

JOHN SLOAT†

ABSTRACT

The three factors considered in this paper are record times, moveouts, and character of echo reflections. It is shown that full-path echoes do not repeat at exact multiples of the primary time when dip is present. It is also shown that certain echoes can not exist when the primary dip is above a critical value. A consideration of echo moveouts on split spreads proves that they are almost exact multiples of the primary moveout up to the critical angle. The equation for the ratio of normal echo moveout to that of the primary is given for the case of single-end spreads, and it is shown that vertical velocities may be computed from echo normal moveouts. The effect of plotting echo reflections by the $x^2 = T^2$ relation is considered. The difference in travel times and moveouts caused by neglect of curved path is shown to be small. Under character, the question of phase inversion of echoes is considered, and the reflection amplitude coefficient for echoes in the Sacramento Valley is computed. An abnormal value for this coefficient is suggested as a requirement for the existence of echo reflections. The conclusion is reached that reflection coefficients large enough to give echoes are usually encountered, if at all, at depths such that the resulting echoes do not interfere with normal interpretation.

The reflection seismograph is over ten years old as we finally discover an area where echo reflections are indisputably present. It is significant that this discovery was made independently and almost simultaneously by several different companies. From this it can be argued that we geophysicists have not been looking out the window all these years, but that echo reflections do not often appear on our records. One may wonder, then, why all this space is being devoted to a discussion of this uncommon seismograph problem.

The answer is that when echo reflections do appear, they can cause serious mismapping of structure. Consider the geologic conditions under which they occur in the Sacramento Valley. The possible productive zones in this area are Eocene and Cretaceous sands which start at about 1,500 feet deep and continue down to granitic basement at 7,000–8,000 feet. Since Eocene times, a basalt flow from the Sierras has covered the area, and this flow (100–200 feet in thickness) is now buried from 1,300–1,500 feet deep, under more recent beds of continental origin. The effect of this basalt sheet on seismograph results is profound. Wave energy generated at the shot points starts its downward trip, only to be reflected back to the surface on striking the basalt. The energy which succeeds in penetrating this layer may then find a suitable reflecting bed in the Eocene or Cretaceous, but when this reflection starts back to the surface it reflects on the *base* of the

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† Union Oil Company of California, Bakersfield, California.

basalt and goes downward again. The resulting seismograms from shot points in this area contain (1) a jumble of reflections which have oscillated back and forth between the top of the basalt and the base of weathering, thus appearing more than once on a single record, (2) reflections which have penetrated the basalt and perhaps oscillated between the base of the basalt and some underground bed before returning to the surface, and (3) true reflections, from Eocene and Cretaceous beds, which have made the usual round trip, with no secondary reflections.

The problem, of course, is to identify the echo reflections so that they will not be computed as coming from true bedding planes below the basalt. A study of three important factors may be helpful in deciding whether echoes are present on a particular record. These factors are: (1) record times, (2) moveouts, and (3) reflection character. The first general case considered is the most common one where reflections occurred between a primary underground bed and the base of weathering (or the surface of the ground), causing reflections from a single bed to appear more than once on a given record. These are called full-path echoes.

Consider first the record time relations for full-path echoes arriving at a geophone near the shot point. If a few assumptions are made, the theoretical travel time for such waves can be computed. The equations involved are shown in Figure 1, under the heading "Shot Point Travel Times." The assumptions are: (1) that some continuous source bed is present which will give echoes, (2) that the travel paths are straight, (3) that the velocity varies with vertical depth only, (4) and that Snell's Law is in effect so that the angle of reflection is equal to the angle of incidence every time a wave hits a boundary. All of these assumptions except the first are frequently made with satisfactory results in reflection shooting.

If the primary bed shown in Figure 1 is flat, then the first echo will return to the shot point at double the primary (T_p-t), the second echo at three times (T_p-t), and so on. The base of weathering is shown as the upper reflector rather than the surface of the ground, as actual records prove that this is true in numerous cases.

As the dip of the primary bed increases, the echo point moves updip both at the base of weathering and on the bed. Consequently, the echo times fall short of being exact multiples of the primary (T_p-t), when dip is present. Figure 1 is drawn to scale for the case where the primary bed is 2,500 feet deep at the point of incidence of the primary reflection, $\tan\theta=0.200$, and the base of weathering is flat. The shot-point travel times for the first three echoes have been computed, using a vertical velocity function derived from well curves in the Sacra-

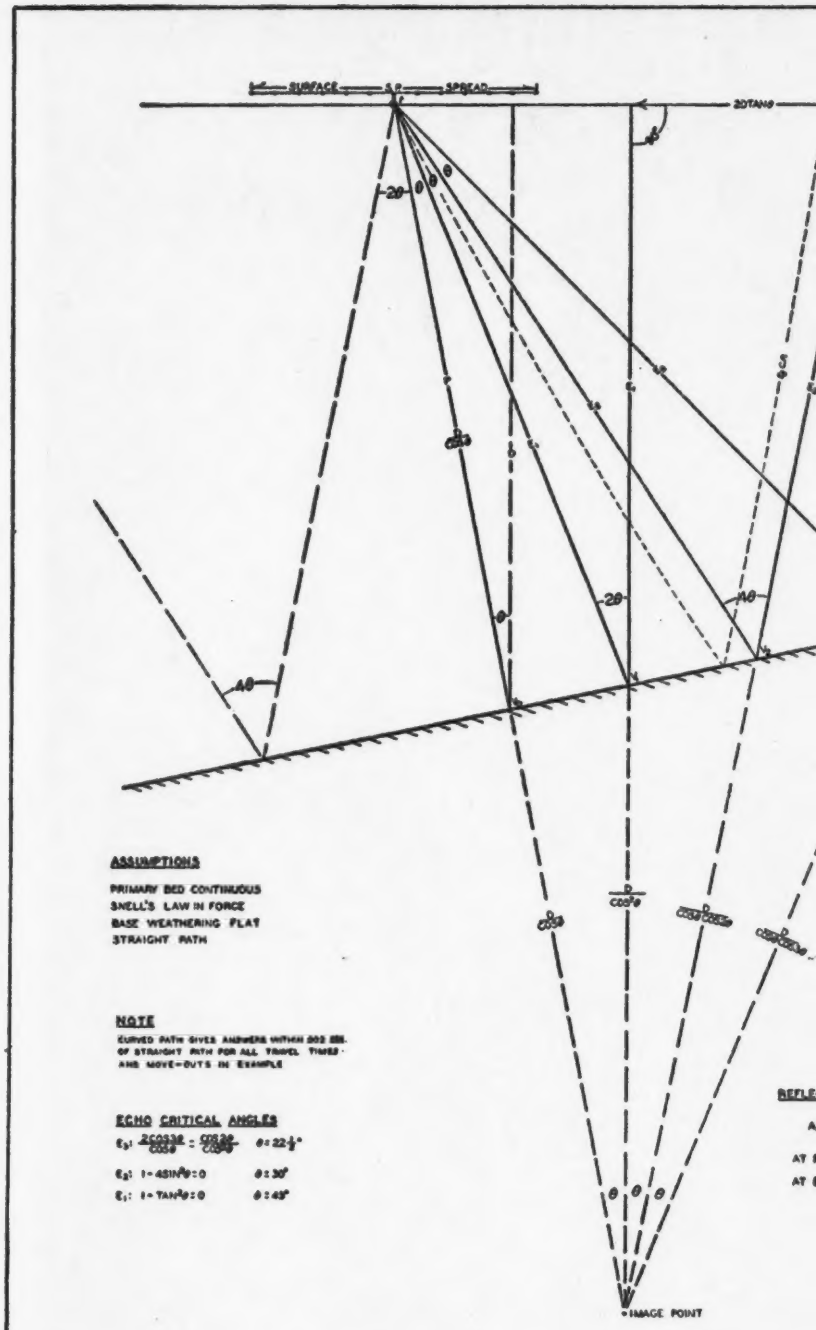
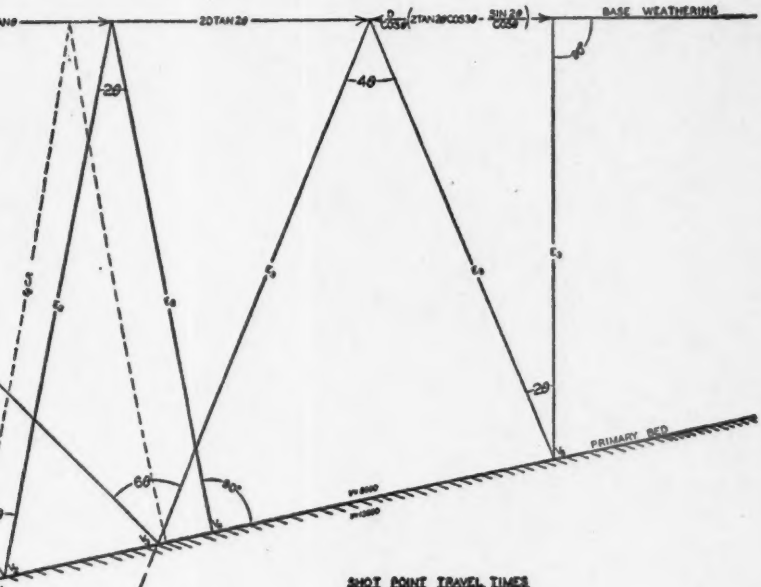


FIG. 1. Shot-point echo travel paths and moveouts over a 600–60
2,500 feet deep and tan $\theta = 0.200$. Other gen



SHOT POINT TRAVEL TIMES

$T_1 = \frac{2D}{V_1 \cos\theta}$ .729

$T_2 = \frac{4D}{V_1}$ 1.434

$T_3 = \frac{2D}{V_2 \cos\theta}\left[\frac{2}{V_1} + \frac{1-4\sin^2\theta}{V_1}\right]$ 2.091

$T_4 = \frac{2D}{V_3 \cos\theta}\left[\frac{2}{V_1} + \frac{\cos\theta\cos 2\theta - \cos 2\theta(1+\cos 2\theta)}{V_1 \cos\theta}\right]$ 2.676

V_0 = AVERAGE VELOCITY TO D		2500
V_1 = " " "	$D(1-\tan^2\theta)$	2400
V_2 = " " "	$D(1-\tan\theta\tan 2\theta)$	2292
V_3 = " " "	$D(1-\tan\theta\tan 3\theta)$	2164
V_4 = " " "	$D(1-4\sin^2\theta)$	2115
V_5 = " " "	$D\left[\frac{2\cos 2\theta}{\cos\theta} - \frac{\cos 2\theta}{\cos^2\theta}\right]$	1834

$T_1 - T_0 = 2D\left[\frac{2}{V_1} - \frac{1}{V_0 \cos\theta}\right]$

REFLECTION COEFFICIENTS

$A_0 = \frac{\rho_0 v_0 - \rho_1 v_1}{\rho_0 v_0 + \rho_1 v_1}$

AT PRIMARY A_0 = .30–.40

AT BASE WX A_0 = .50–.75

MOVE-OUTS ON 600-600 SPLIT

D=2500 TANθ=.200

ΔT_0 = .0317 sec.

ΔT_1 = .082

ΔT_2 = .092

ΔT_3 = .118

NORMAL MOVE-OUT — SINGLE-ENDERS

$\frac{\Delta T_D}{\Delta T_{ND}} = \frac{\sqrt{X^2+4D^2} - 2D}{\sqrt{X^2+(2N+2)^2D^2} - (2N+2)D}$ N IS NUMBER OF ECHO

$\Delta T_1 = \frac{1}{2}\Delta T_2$

$\Delta T_2 = \frac{1}{3}\Delta T_3$

$\Delta T_3 = \frac{1}{4}\Delta T_4$

600–600-ft. spread are shown for the case where the primary bed is
her general relations for echoes are also shown.

UNIV. OF MICH.

mento Valley where echoes are obtained. Notice that the first echo is 0.024 second short of doubling the primary ($T_p - t$), the second echo is 0.096 second short of tripling the primary time, and the third echo is 0.240 second short of quadrupling the primary time. Putting this another way, the time interval between the second and third echoes is only 0.585 second as compared to a time interval between the primary and first echo of 0.705 second.

If the dip of the primary bed is as much as 22.5°, no echoes beyond the second can exist, because in this case the projected bed would outcrop at the farthest point of incidence of the third echo. This is true regardless of the depth of the primary bed. At 30°, no echoes beyond the first can exist. This does not mean the primary bed must actually crop out, but rather that when the local dip is as much as 20°, one will be lucky (or unlucky) to receive more than one echo if any at all. Conversely, if a number of echoes are received, and the time interval between echoes is about the same, then the primary bed is fairly flat regardless of indicated record moveouts.

There is probably another reason why repeated echoes will not be observed where the primary dip is much over 10°: observe the path for the third echo in Figure 1. The angle from the shot point to the bed is such that a considerable portion of the wave energy may travel up the bed as a refraction, thereby decreasing the reflected energy to the point where no echo will be observed.

One other comment about travel times is in order. Assume one has a record where several echoes can be recognized, and the shot-point time intervals between echoes can be accurately counted. If ideal conditions are assumed, then the dip of the primary bed and the vertical velocity function can be computed from these time intervals. However, this method has low resolving power and a slope in the base of weathering or change in primary dip can cause wrong answers.

The second important factor to consider in identifying echoes is the record moveout. In Figure 1 a 600-600-foot split spread is shown, but to minimize confusion the echo travel paths to the end seismometers are omitted. Echo paths for the shot-point seismometer are shown. Under the assumptions made for Figure 1, the moveouts for the primary and first three echoes have been computed. Without going into the equations involved, the results are as follows: ΔT primary is 0.032 second. The first echo moveout is 0.062 second, or almost double; the second echo moveout is 0.092 second, which is only 0.004 second short of tripling the primary; and the moveout on the third echo is only 0.011 second short of four times the primary moveout. Similar relations will be found for dips up to about 20° where third echoes cease to exist. If the primary bed is deeper than in the example, or if its dip is

less, or if the surface spread is shorter, or if the slope of the velocity-depth curve is greater, then the echo moveouts will be more nearly exact multiples of the primary moveout. The reverse of any of these conditions will tend to make the echo moveouts less than exact multiples of the primary.

On actual records it is sometimes found that the echo moveouts are not in conformity with the above theory, particularly when the primary moveout is greater than 0.010 or 0.015 second. This can be explained by inexact weathering corrections, flexuring of the bed, or slope of the base of weathering. Incidentally, approximately the same surface-spread weathering corrections which are applied to the primary moveout, are likewise applicable to echo moveouts, since the echoes are thought to be reflected from the base of weathering. If it can be proved in a given case that the surface of the ground is the reflector, then the primary weathering correction will be different from that for each echo.

For those who are concerned about the assumption of straight path in Figure 1 it might be well to state that this example has also been computed using curved-path theory based on the widely used linear-depth law. The dotted line indicates the computed wave path of the second echo. The effect of a curved path is to move all echo and reflection points down dip. However, all moveouts and travel times check within ± 0.002 second of the values given by straight-path computations, and the shortening of the echo time intervals with increased dip of the primary bed is still evident. Incidentally, the simple angular relations for echo paths shown in Figure 1 do not apply when curved paths are assumed.

So far only split or offset-T spreads have been considered. The case of single-end spreads is of particular interest because echo moveouts on such spreads may be used as a check on vertical velocity determinations. Consider a single-end (or end-on) spread stretching from the shot point to a distance x from the shot point, and imagine a flat bed at D depth below weathering, the base of weathering being a horizontal plane. Now consider that primary and echo reflections are recorded. The ratio of the primary moveout to echo moveout is given by the equation

$$\Delta T_P/\Delta T_{EN}=(\sqrt{x^2+4D^2}-2D)/(\sqrt{x^2+(2N+2)^2D^2}-(2N+2)D), \quad (1)$$

where N is the number of the echo being considered. Notice that the radical in the numerator gives the travel path for the primary to x distance, and that the radical in the denominator gives the echo travel path for the same distance.

Since the ratio $\Delta T_P/\Delta T_{EN}$ can be read from the record, and since

x is known, it might seem that D could be computed from Equation (1). But this is like the case of adding a 50-foot length to a tight steel band girdling the earth, and then being able to walk under it when the link is evenly distributed—it is possible mathematically but purely hypothetical from a practical standpoint. A closer look at Equation (1) shows that its resolving power depends on the ratio of the spread length to the bed depth. And since the ratio of $\Delta T_P/\Delta T_{E_1}$ (for example) varies from about 1.9 to 2.01 in actual practice, an error of a few thousandths of a second in reading either the primary or echo moveout might mean the difference between computing the depth as being up in the air or somewhere deep within the earth.

The importance of Equation 1 is that it shows that the normal moveout on the first echo is almost exactly half that of the primary reflection; the moveout on the second echo is one-third that of the primary; the moveout on the third echo is one-fourth that of the primary, etc. This is not to be confused with the statements made concerning moveouts on split spreads. In that case we were dealing with moveouts caused by dip of the primary bed, and in the present case with the normal moveout on single-enders when the primary bed is flat. The two are related in this way: If a split spread is shot where the primary bed and base of weathering are both flat, then the moveout pattern on the split spread should show half as much moveout on the first echo between the outside and center traces as does the primary reflection, the net moveout from top to bottom trace being zero, of course, for both the primary reflection and first echo.

Echo moveouts on single-enders may be of considerable value in computing velocities. Indeed, it can be shown that weathering corrections and dip tend to cancel out on echo reflections when the moveouts on the fore shots and back shots of single-enders are averaged together. In other words, they may be dealt with in a manner similar to that commonly used when computing velocities on a primary reflection. In fact, moveout caused by the dip of the bed tends to cancel more completely on the first echo than on the primary, because the bed coverage on the first echo is over more nearly the same portion of the bed on the fore shot and back shot. However, when dip is present, the average velocity obtained by computing the first echo will be the average velocity to a vertical depth which is somewhat less than the vertical depth for the average velocity given by the primary moveout determination.

Here is a case related to the above discussion. Assume you have shot a 2,000-foot single ender for the purpose of making a customary x^2-T^2 determination for vertical velocity. Assume, furthermore, that two good reflections are present on the record, and that you do not

know whether the second pulse is an echo of the first, so you proceed to compute it as a regular reflection. Figure 2 shows how the x^2-T^2 plot will appear if the primary bed is flat at a depth of 2,500 feet and the vertical velocity function is the same as that used in Figure 1. For those unfamiliar with this sort of plot it can be stated briefly that

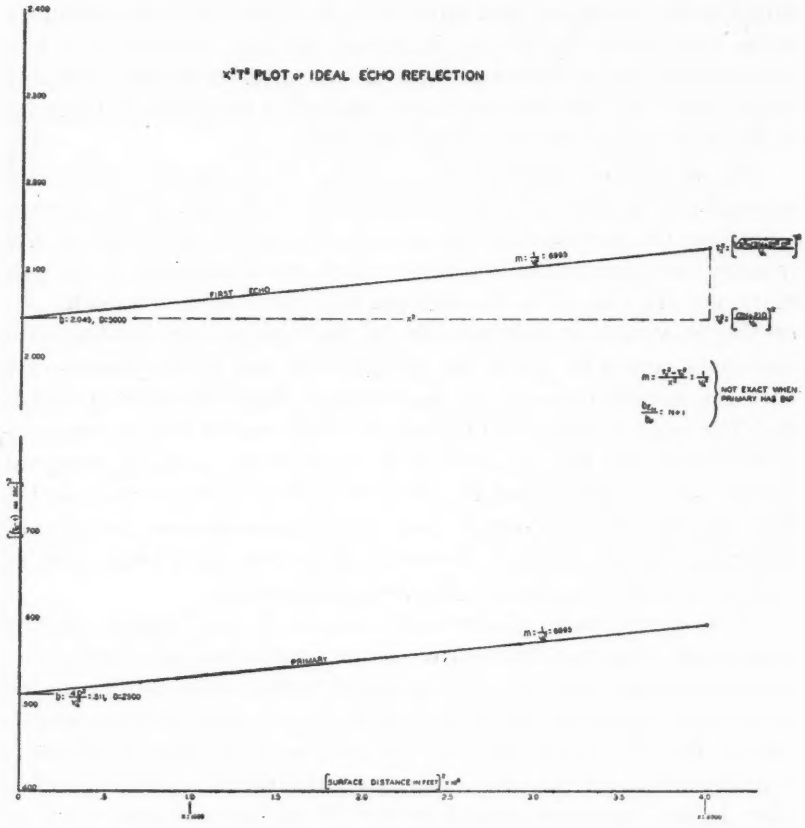


FIG. 2. This x^2-T^2 plot for a 2,000 ft. end-on spread shows how an unsuspected echo would appear when computed for vertical velocity.

the squares of surface seismometer distances are plotted along the x-axis and the squares of reflection times, to corresponding seismometers, are plotted along the y-axis. The slope of the plot of a given reflection is $1/V_A^2$, where V_A is the average vertical velocity to the bed.[1]

In the case at hand the velocity of the primary comes out as 6,995

[1] See, for instance, Nettleton, *Geophysical Prospecting for Oil*, pp. 284–285.

ft/sec. Notice that the slope of the second reflection—which is actually the first echo of the primary—gives exactly the same velocity, with the computed depth being exactly twice that of the primary. A consideration of Equation (1) and the nature of x^2-T^2 plots will show that all echoes will give the same velocity as, and multiple depths of, the primary when the primary bed is flat. If the primary bed has dip, then the velocities shown by the multiples will be progressively lower than the primary, and the computed depths will be progressively shorter of being exact multiples of the primary depth. It can be seen that x^2-T^2 plots may be of value in the identification of echo reflections.

All of the above discussion deals with full-path echo reflections. Another general case which has been observed is that where reflecting beds are present above the primary echo generator. If enough energy is returned to the surface from the primary and then reflected downward again at the base of weathering, this echo energy may sometimes be strong enough to cause secondary reflections from beds above the primary as well as multiples of the primary reflection. The effect is much the same as if a new shot had been fired at the moment the primary reflection reached the base of weathering, except that the shots would be everywhere along the base of weathering instead of only at the shot-hole. The result is that numerous reflections above the primary are repeated on the record, in addition to multiples of the primary. The upper beds do not give echoes from their own reflected energy, but from energy impinging on them from echoes off the primary bed below.

For moveout and record time relations for this case, consider a simple arrangement where a primary bed is present as in Figure 1, with an added sedimentary reflecting bed several hundred feet above the primary. Let the bed above the primary have a different dip from the primary. When a shot is fired, a reflection from the sedimentary bed will appear, then a reflection from the deeper primary, then an echo from the sedimentary bed (caused by energy from the primary) then the first echo of the primary, etc. The problem is: "what will be the record time and moveout of the sedimentary reflection when it appears the second and third time on the record?"

Let T_s be the original reflection time of the sedimentary reflection to base Wx, ΔT_s be the original moveout of the sedimentary reflection on a split spread, T_p be the original time of the primary to base Wx, and ΔT_p be the original moveout of the primary.

A study of this problem shows that the sedimentary reflection will make a second appearance on the record at a time of T_s+T_p and will have a moveout of $\Delta T_s+\Delta T_p$. If the sedimentary reflection appears for a third time, it will do so at a record time of $2T_p+T_s$ and have a

moveout of $2\Delta T_p+\Delta T_s$. These values are approximate because of the shortening of time interval and moveout caused by dip, as previously mentioned, in the discussion of full-path echoes.

Another general case is where energy from the shot penetrates an upper reflector, reaches a reflecting bed below it, oscillates between the two beds and finally returns to the surface. This type of multiple is referred to as an inter-bed echo. Record times and moveouts for such reflections can be derived for an assumed case, but as far as is known, no actual examples of this type of echo have been observed. It is sincerely hoped that few exist, for echoes of this type, unaccompanied by obvious full-path echoes from either reflector, could cause the most serious type of mismapping of structure, particularly if the two reflectors were separated several thousand feet in depth.

The third factor to consider in the identification of multiples is reflection character. Some echoes can be spotted immediately by pulse and phase reproduction alone. In other cases, where the primary itself is of low quality, this identification is difficult.

One important question concerning character is phase inversion. If a trough pick is made on the primary, should a trough or peak pick be made on the first echo? This is not easy to answer from actual records, as some first echoes check better when picked the same as the primary, and others do not. One difficulty is the identification of the onset of the reflection, and the possible reduction in frequency of echoes caused by their longer time of transit within the earth. Theoretically the phase relation can be determined from the equation for the reflection coefficient. This equation can be found in several publications[2–3] and is given by

$$A_0 = (\rho_2 V_2 - \rho_1 V_1)/(\rho_2 V_2 + \rho_1 V_1) \qquad (2)$$

where A_0 is the ratio of the amplitude of the reflected wave to that of the incident wave, ρ is the density of the medium, and V the velocity in the medium. The A_0 given is for waves striking normal to the bed, but its value does not change very rapidly until large angles of incidence are encountered. There are other restrictions on the validity of this equation; nevertheless, it is useful in a rough analysis of the present problem.

For the case at hand, we find that the velocity of the basalt in Northern California is at least 13,000 ft/sec, whereas the velocity in the Miocene above the basalt is not over 8,000. The density of the basalt was not actually measured, but the drilling rate supports a figure of 3 gm/cm^3, given in most tables. The density above the basalt

[2] S. S. West, GEOPHYSICS, Vol. 6, pp. 45–51, 1941.

[3] L. B. Slichter, *Gerlands Beiträge zur Geophysik*, Vol. 38, pp. 228–256, 1933.

is assumed as 2.4 gm/cm³, which is an average figure for Miocene shale in the San Joaquin Valley. We have, then: $\rho_1 = 2.4$, $\rho_2 = 3.0$, $V_1 = 8{,}000$ and $V_2 = 13{,}000$. The reflection coefficient is, therefore, 34 percent, or even higher if optimum values are used. This is truly a remarkable figure when you consider that the reflection coefficient for an ordinarily good reflection is from 3 to 10 percent and that the Vedder reflection, usually considered one of the best in the Southern Valley, has a coefficient of only 3 percent.

The phase of the reflected wave is given by the sign of the numerator of Equation (2). For the basalt this is positive because $\rho_2 V_2$ is greater than $\rho_1 V_1$. The reflected longitudinal wave is therefore in phase with the wave arriving from the shot. Now consider what happens to the wave as it impinges on the base of weathering, and is returned to the basalt. At the base of weathering $V_1 = 6{,}000$, $V_2 = 2{,}000$, ρ_1, the density below weathering, is estimated as 2, and ρ_2 of the weathered zone as 1.2. The reflection coefficient is, therefore, 67 percent. Even if the densities are assumed the same, the coefficient is 50 percent. And notice that in this case $\rho_1 V_1$ is greater than $\rho_2 V_2$ so that the wave reflected downward from the base of weathering is reversed in phase. From this it can be reasoned that the first, third, and fifth echoes will be 180° out of phase with the primary on a given record, while all even numbered echoes will be in phase. This has yet to be proved in practice.

Since so large a percentage of incident energy is reflected downward from the base of weathering, even under normal shooting conditions, it is easy to wonder why we do not obtain echo reflections all the time. The answer may be that we do not often encounter reflection coefficients on underground beds which are large enough to return suitable energy to the base of weathering. Another factor is that although such coefficients may sometimes be found, the depth of the primary bed will usually be great enough (basement, perhaps) that echo reflections will not interfere with or even appear on records of normal length. It can be concluded that echo reflections do not often interfere with normal interpretation in most areas; but when they do appear, any treatment should include aspirin for the interpreter.

DISCUSSION ON DOUBLE REFLECTIONS*

FRANK ITTNER†

It has been known for some time that double and multiple reflections have in many areas tended to confuse and, in some cases, override entirely the information that was intended to be recorded. As Mr. Ellsworth has pointed out, the Chico region in the Sacramento Valley is one of these areas. Conditions there are quite good for the development of multiple reflections because of the near-surface layer of basalt which acts as an excellent primary reflector, and the presence of a thin and uniform weathered layer in combination with a regular topography.

Very little is known about the action of the double reflection, but in its simplest form it is presumed that the energy from the shot is

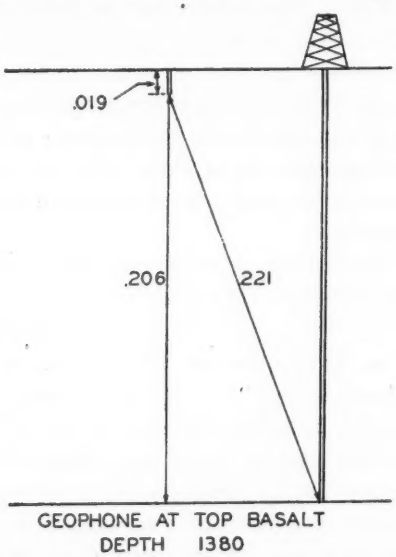


FIG. 1. Setup for the velocity survey of Superior's Dodge Lands No. 1, Butte County, California

reflected from a flat-lying bed possessing a high coefficient of reflection and then travels toward the surface where it is reflected down again with change of phase at the base of the low-velocity layer or the surface of the ground, or both. Thus, a new wave is set up which is quite similar to the original one as initiated by the shot.

* Presented at the Los Angeles Meeting of the Society November 7, 1946. Manuscript received by the Editor January 6, 1947.

† The Superior Oil Company, Los Angeles, California.

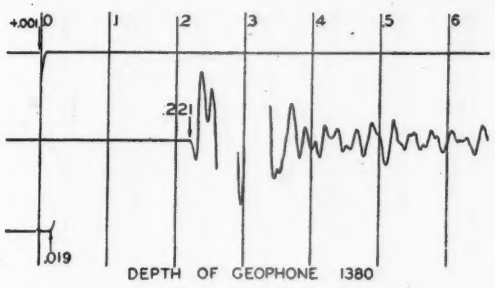


FIG. 2. Copy of record taken by geophone at top of basalt.

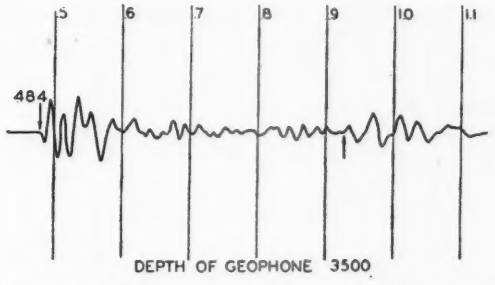


FIG. 3. Copy of well seismometer record at depth 3,500 feet.

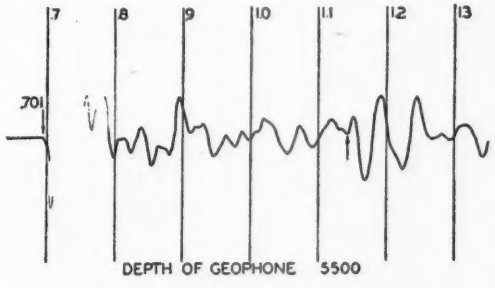


FIG. 4. Copy of well seismometer record at depth 5,500 feet.

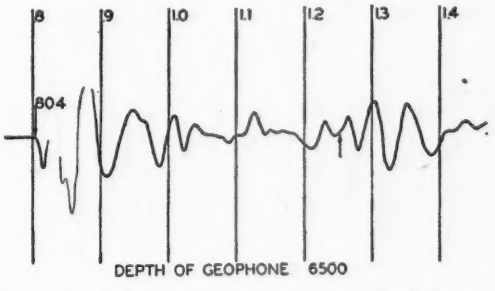


FIG. 5. Copy of well seismometer record at depth 6,500 feet.

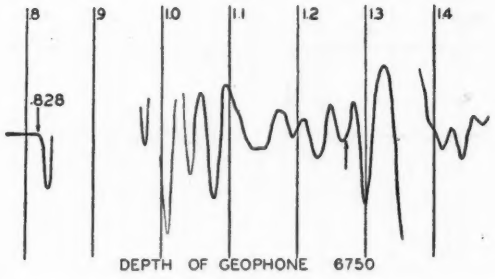


FIG. 6. Copy of well seismometer record at depth 6,750 feet.

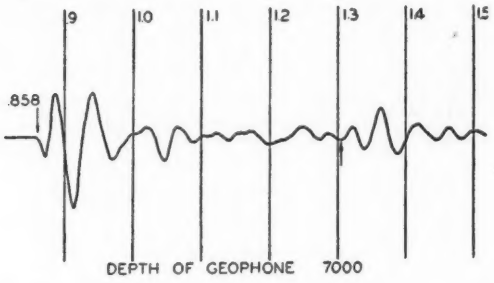


FIG. 7. Copy of well seismometer record at depth 7,000 feet.

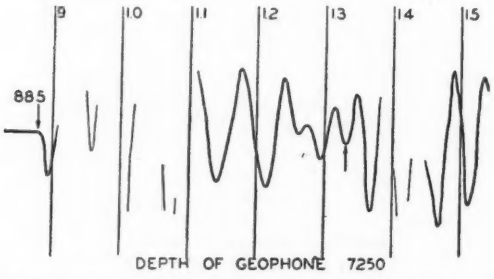


FIG. 8. Copy of well seismometer record at depth 7,250 feet.

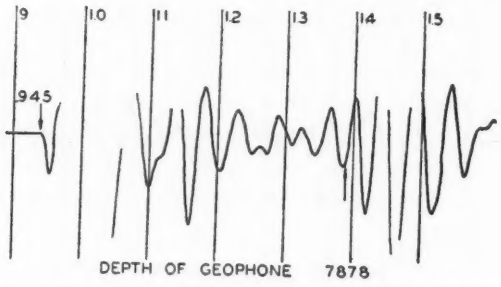


FIG. 9. Copy of well seismometer record at depth 7,878 feet.

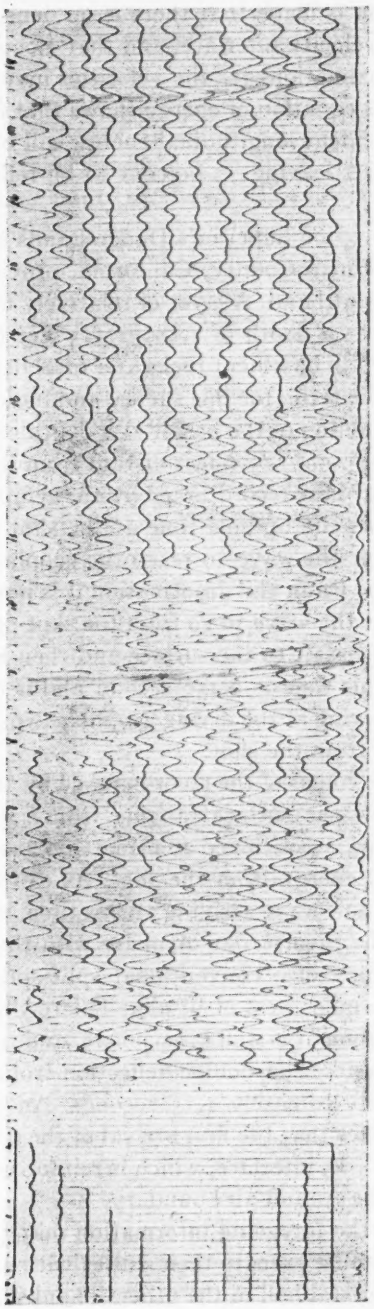


FIG. 10. Split record taken 3 miles west of Visalia, Tulare Co., California, showing at 1.75 second the double reflection of top of basement.

If the assumption is made that there is no density change at the low velocity—high velocity interface, and that 2,000 ft/sec and 6,000 ft/sec are fair approximations for the velocities involved, then a consideration of Knott's equation of energy shows that for a vertical ray, 25 percent of the incident longitudinal energy will be reflected at the low velocity interface, leaving 75 percent to be reflected at the free boundary.

The velocity survey on Superior's Dodge Lands No. 1, Section 31, T. 20 N., R. 1 E., Butte County, California, provides fundamental data for the problem at hand. A layer of relatively flat-lying basalt is present in this well at a depth of 1,380–1,513 feet from the surface. The well was stopped in basement rocks at a total depth of 7,888 feet.

Figure 1 shows the setup for this survey and indicates the position of the geophone at the top of the basalt at a depth of 1,380 feet below the surface. The shot point is 500 feet distant from the well.

Figure 2 is a copy of the record taken by the geophone at the top of the basalt, and shows the up-hole time at the shot point (0.019 second) and the time for the wave to reach the geophone from the shot point (0.221 second). From this information it is possible to compute the time required for the wave to go from the shot point to the top of the basalt, from the basalt to the surface and then back again to the top of the basalt. This time is 0.450 second and is the time that the double reflection arriving at the diving geophone would lag the arrival of the initial energy from the shot.

Figures 3 to 9 are copies of the records made by the well seismometer at depths below the surface ranging from 3,500 to 7,878 feet. In each case the arrow is positioned at a time of 0.450 second after the arrival of the initial energy from the shot. As can be seen, there is ample evidence of a new wave arriving at this time, which is, as would be expected from the theory, out of phase with the original energy.

Figure 10 is a copy of a conventional split-spread record taken approximately three miles west of Visalia, Tulare County, California. The depth of the basement is well known here, and is indicated by the reflection at 0.9 second. The double reflection from the basement is clearly shown at approximately 1.75 seconds. An inspection of the time involved indicates that the first arrival of the double reflection is probably from the V_1-V_2 interface, which is reinforced a cycle later by the reflection from the ground-air boundary.

It is hoped that the foregoing information may prove of some interest to those who must execute their duties with a reflection record in one hand and a crystal ball in the other. Thanks are due to Walter A. English for helpful suggestions, and to Dale Turner for preparation of the slides.

MULTIPLE-REFLECTION EVIDENCE*

JOSEPH C. WATERMAN†

A rather interesting example of multiple reflections was found in one area in Madera County on the east side of the San Joaquin Valley of California. In this region the top of the basement complex is an excellent reflecting horizon, and the determination of the depth of the basement was confirmed by well data.

Figure 1 shows the seismic profile for the line on which the multiples were observed. The well, shown near the right end of the line found basement at about 2,750 feet subsea, as indicated, but numerous events of good quality were observed at arrival times greater than that of the basement reflection. The possibility of these events representing reflection planes within the basement was precluded by the observation that the velocity determined was much slower than basement velocity.

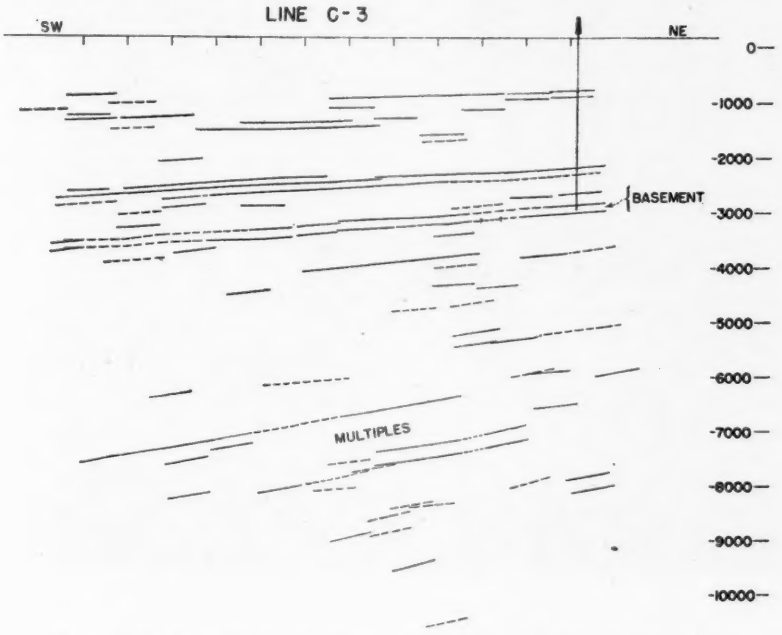


FIG. 1. Seismic profile for the line on which the multiples were observed.

* Presented at the Los Angeles Meeting, November 7, 1946. Manuscript received by the Editor September 29, 1947.

† Shell Oil Company, Inc., Bakersfield, California.

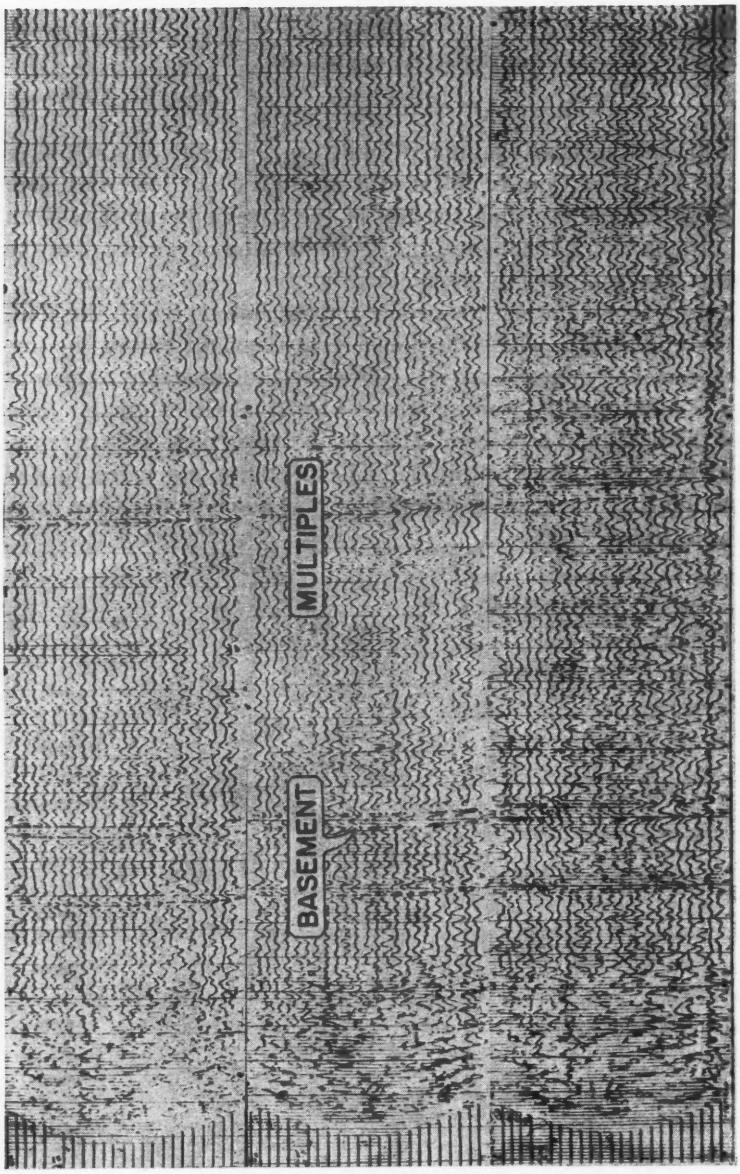


FIG. 2. Seismogram specimens from three adjacent "straddle" spreads.

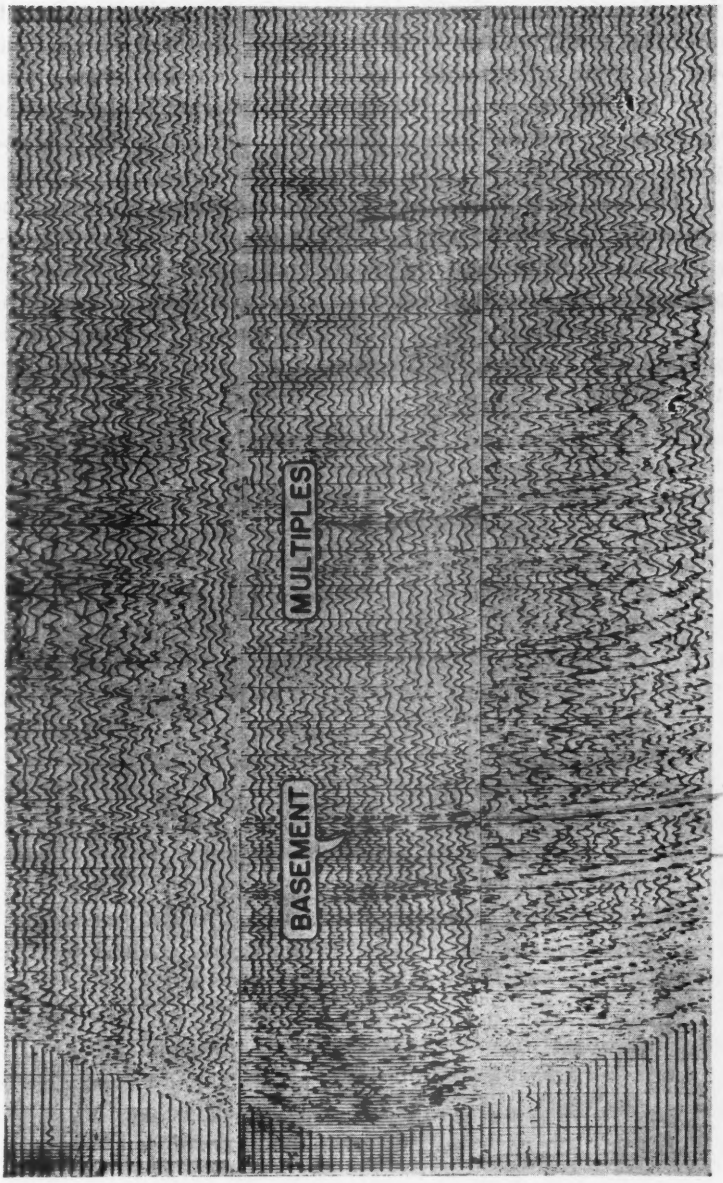


FIG. 3. Seismograms covering same subsurface spread as those of Figure 2, with outside ones from "oblique" shooting.

Seismogram specimens in Figure 2 are from three adjacent "straddle" spreads of continuous profiling. In Figure 3 the three seismograms all cover the same subsurfacing spread, but the outside seismograms are from "oblique" shooting. The center seismogram is the same in Figures 2 and 3, and on it are marked the basement reflection and multiples.

It is of interest to note that there are four or five events beyond the basement reflection which appear to repeat at quite regular intervals. There is some evidence that the events may not all be multiple reflections between basement and surface or between basement and the base of the weathered zone, but that at least some of the energy could be from multiples between the basement and the strong sedimentary reflecting horizon.

REMARKS ON MULTIPLE REFLECTIONS*

B. GUTENBERG† AND C. Y. FU†

One cannot help being impressed by the wonderful arrays of seismograms depicted in Mr. Ellsworth's paper and in the prepared discussions. The regularity of the time intervals of successive impulses and the alternating sequence of the change of phase are readily adapted to a mechanism of multiple reflections. If the latter is accepted, the following questions seem to merit some consideration: (a) the energy concentration, (b) the positions of the reflecting surfaces, (c) the sharpness of the source-impulse, and (d) the velocity contrast of the adjacent media.

Even if the absorption of the ground could be entirely neglected, the intensity of energy of a seismic disturbance undergoing multiple reflections would be diminished for at least two reasons. First, the energy may be spread out owing to the divergence of the pencils of rays as shown in Figure 1a. This is true when the reflector is a plane. When it is a syncline or a depression as shown in Figure 1b, the spreading may be compensated by the curvature of the reflecting surface. There may even be a focusing effect if the curvature is very favorable, e.g., one optimum focusing is obtained if the surface is a sphere around the source.

Secondly, the amplitude of the disturbance is decreased after each reflection as shown in Figure 2a, because a part of the energy must be transmitted. Since there is no perfect reflector of seismic waves in nature, a multiple reflecting layer can never be a conservative system. The loss depends on the transmission coefficient of the interface and cannot be compensated by any converging effect of the reflecting surface. But there might be an accumulation effect in the manner as shown in Figure 2b, if the source is not a sharp pulse, but of finite extent.

In the configuration described in Mr. Ellsworth's paper, there are two regions in which multiple reflections might travel: the disturbance may be multiply reflected by the earth's surface and the upper surface of the basalt or, it may be multiply reflected by the upper and lower surfaces of the basalt bed itself, this latter being rather thin. One can, of course, decide which of these alternatives is responsible for the

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† California Institute of Technology, Pasadena, California.

Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California, Contribution No. 403.

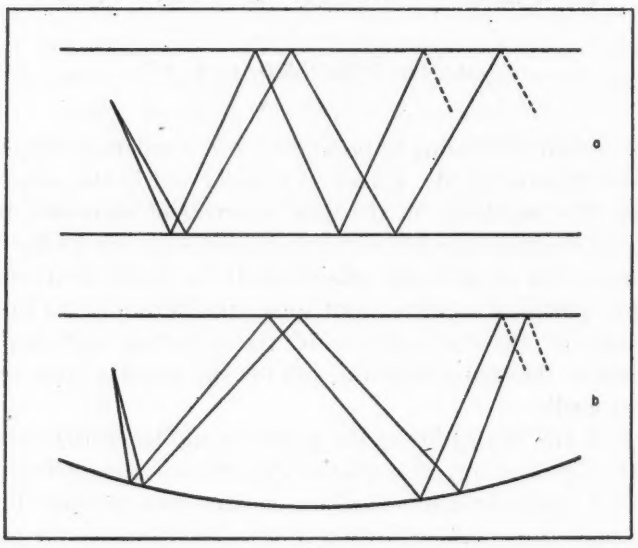

FIG. 1. (a) Energy dispersion by divergence of rays from plane reflector. (b) Concentration of energy by concave reflecting surface.

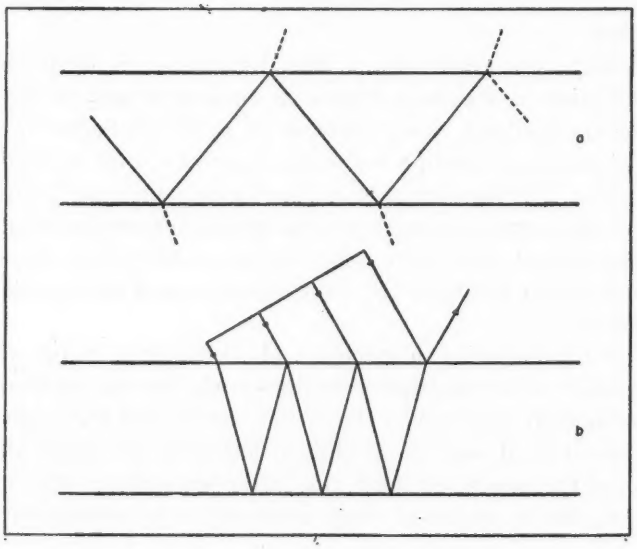

FIG. 2. (a) Energy loss by imperfect reflection. (b) Accumulation effect for source of finite extent.

multiple reflections observed by the time intervals of the successive impulses.

One might doubt whether sufficient reflection at ground surface would occur, because the transition from the weathering layer to the subweathering medium is usually a gradual one and this transition zone is not a good reflector. However, under suitable circumstances, this reflection *is* observed. The *pP* phase in seismology is frequently well recorded. In seismic prospecting, surface reflection has been reported by Leet[1]. The reason for this is that for the long-wave component of the source, the weathering layer is too thin to give appreciable effect and the reflection really occurs at the free surface. On the other hand, the thin basalt bed can hardly affect the long waves. But for a source of the form of a sharp pulse, it is not impossible that multiple reflections may also occur in the thin bed.

The phase relations of the successively reflected pulses depend on the contrast of properties of the contiguous media. The theory has been worked out by Sezawa[2–3] who treats the multiple reflections in a surface layer, but certainly the general nature would be similar for an inner bedding. To illustrate the relations, we reproduce below two of his graphs in which H is the thickness of the layer, c, a parameter signifying the width of the pulse, μ' and μ are the rigidities of the layer

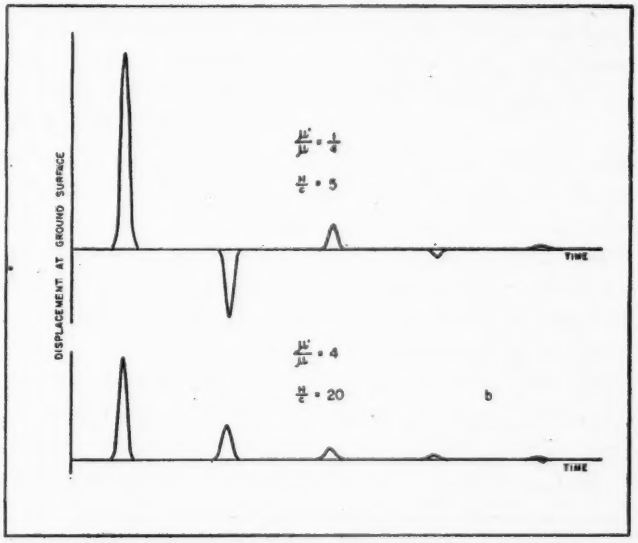

FIG. 3. (After Sezawa) Phase relations in multiple reflections.

[1] L. Don Leet, Bull. Seism. Soc. Am., 27, 97–98, 1937.
[2] K. Sezawa, Bull. Earthquake Res. Inst. Tokyo, 8, 1–11, (1930).
[3] *Ibid.*, 13, 251–262, (1935).

and the lower medium respectively, and the Poisson ratio of both being assumed equal to 1/4. It is seen from these graphs that the phase may or may not change depending on the relative rigidities.

Finally, it may be of interest to point out that in multiple reflections, the over-all reflection and transmission coefficients depend on both the ratio of the thickness of the reflecting layer to the wavelength and the frequency of the wave component even when the latter is plane, homogeneous, and of infinite extent. This can obviously be inferred from the theory of parallel plates in physical optics. Hence, the coefficients as ordinarily calculated for an interface of two semi-infinite media are quite inadequate in the present case. The indiscriminate application of them might lead to misleading results.

THE EXISTENCE OF MULTIPLE REFLECTIONS*

C. HEWITT DIX†

On several occasions during the past several years, various geophysicists have expressed, in private discussion, doubt regarding the existence of multiple reflections or at least their recordability over background noise. Hence the following comments.

Suppose the reflection coefficient for the primary reflection is 0.1. Let the secondary reflectors be the weathering base and the top of the ground, allowing a 0.5 reflection coefficient for each. Suppose the primary reflection is positive, i.e., an incident compression is reflected as a compression. The secondary reflections are always negative. Therefore the simple double reflection is always negative. The double reflection from the base of the weathering will then be 0.05 as strong as the primary reflection neglecting inverse-square distance effects and absorption. Roughly the double reflection will be at least 0.01 as strong as the single. The required increase in sensitivity during the time from the primary reflection to the double would be about 40 db. Doubling the original reflection coefficient reduces the expansion rate required by about 6 db. Such expansion rates are used fairly frequently. Intensities of multiple reflections are occasionally greatly increased by concave curvature of the reflecting surface or surfaces. I have probably much overcorrected for distance and absorption losses. Without this correction the gain change would have to be nearer to 25db instead of 40 db.

Two independent criteria may be used to identify multiple reflections: (a) careful timing and (b) reflection time vs. horizontal distance. In the first case the beginning of the primary reflection should be good enough to pick within ± 0.005 seconds. If the double comes from the base of the weathering, the single reflection should be reduced to this datum. Then the double (reduced to weathering base) reflection's time will be double the single reflection's time. Similar remarks apply for the double reflection involving the top of the ground. Care must be exercised in matching troughs on the positive single with peaks on the negative double reflection, or troughs on the negative single with troughs on the negative double reflection. This matching is often possible and serves to help make the accuracy of determination of the beginning of the primary reflection very much better. The matching of times gives a condition which is implied by the existence of multiples but does not itself imply the existence of multiples.

* Manuscript received by the Editor January 24, 1947.

† United Geophysical Company, Inc., Pasadena, California.

The second criterion is however almost sufficient to imply the existence of a multiple reflection. These abnormally large time moveouts have been observed so many times in special spreads laid out for velocity determinations by so many people that no further comment need be made relative to the existence of this "t_x vs. x" effect.

When the moveout $(t_x - t_o)$ is abnormally high *and* criterion (a) is satisfied, one is justified in classifying the reflection as a multiple. When one of the criteria is satisfied but not the other the probabilities of alternative explanations other than multiple reflections are increased. When neither criterion is satisfied the evidence for the existence of multiples is usually very weak. Other kinds of evidence may call multiples to our attention, such as a cross section with deep small dips cutting through an anticline with large dips (the small dips being from multiples of the gently dipping upper section), or such as the case of a reflection appearing above the basement (igneous) on one part of a seismograph line and below on another part, cutting across the basement in between the two parts.

The evidence for the existence of multiple reflections does not yet make their existence "strictly certain" but the non-technical layman would consider that the difference between "certainty" and "the probability of the hypothesis of the existence of multiple reflections" is technical hairsplitting and probably he would be correct.

DISCUSSION OF MULTIPLE REFLECTIONS*

O. C. LESTER, JR.†

ABSTRACT

A field experiment designed for the purpose of recording and identifying sound reflections from the surface of the earth is described. Shot and recording points at varying depths in adjacent deep holes were used. This experiment was performed at several locations in the Mid-Continent and Gulf Coast areas. No evidence of reflections from the ground-air contact was observed.

DISCUSSION

The general subject of multiple reflections includes two possible types: (A) the type involving more than one reflection at subsurface interfaces, and (B) the type involving reflection from the surface of the earth. The following discussion pertains only to the latter type.

Data on which this discussion is based were obtained in 1935 and 1936 by a Geophysical Research Corporation experimental reflection party under the direction of W. T. Born of the Tulsa Laboratory. The party chiefs and authors of the reports freely quoted herein were Mr. H. M. Houghton and Mr. W. B. Kendall.

The experiment to be described consisted essentially of shooting and recording at subsurface positions, in deep holes, in attempts to record and identify energy reflected from the surface of the ground.

DIAGRAM

Figure 1 is a diagram of the field setup used. Two holes were dug, fifty feet apart. Shots were fired from hole *A*, at various depths, and recorded in hole *D*, at various depths. A surface detector was placed at point *B*, the predetermined point of reflection for the several combinations of shot and recorder depths. For each recording depth *D* an additional shot was fired at this same position and recorded at surface position *B*, or vice versa. Obviously, the sum of the two recorded times for the paths *A-B* and *B-D* should be equal to the reflected path time *A-B-D*, and hence the exact arrival time of the reflection was determinable. A surface detector at position *C* was used only for check purposes.

The following is quoted from Mr. Houghton's report on experiments performed at two locations near Shawnee, Oklahoma:

"At the first location the geophone hole was deepened from 25 feet to 150 feet in 25-foot intervals; charges were fired at 85 feet,

* Presented at the Los Angeles Meeting of the Society, November 7, 1946. Manuscript received by the Editor December 16, 1946.

† Amerada Petroleum Corporation, Los Angeles, California.

where the shot hole had bridged. No evidence of energy reflected from the surface was observed.

"At the second location charges were fired at varying depths from 127 feet to 160 feet, depending on the amount of caving in the hole. Recording depths varied from 78 to 184 feet in approximately 25-foot intervals.

"At the second location, with a recording depth of 127 feet and a shot depth of 135 feet, there appeared an energy burst with the proper time to be a surface reflection. The geophone hole was carried deeper in the hope that the possible surface reflection might continue at the greater depth, but such was not the case. At all positions other than the one mentioned above, there was neither a sufficient change in the energy level nor was there any burst at the proper time.

"It has been suggested that the surfaces used were not sufficiently smooth to produce good reflections. Another explanation of lack of results is the variation of velocity laterally very close of the surface."

Several short refraction profiles were apparently shot for the purpose of determining the magnitude of near-surface velocity variations mentioned in the report. Comparatively large velocity variations were indicated by these data.

Sketches accompanying the report indicate a slight but uniform slope between the shot and recorder holes in the first location. In this case both holes were drilled in the drainage ditch on the same side of the road. The topographic cross section at right angles to the line of shot might be considered rough. In the second location both holes were moved across the drainage ditch into a grassy field. The surface at this location appears quite smooth.

A similar experiment to the foregoing was performed in the Guthrie area of Oklahoma with the geophone fixed at the bottom of one hole and shot depth varied from 15 feet to 215 feet in approximately 25-foot intervals. I quote briefly from Mr. Houghton's report on that work:

"No sign of a surface reflection was seen on any of the records."

Subsequent to the work reported above some experimenting was done, along similar lines, in an area in Kansas where the Cimarron limestone is very shallow. Unfortunately, no written report of this work is now available but it is my recollection that similar deep-hole shooting and recording was done without obtaining surface reflections. Many high amplitude records, taken from a normal shooting and recording setup on the surface, were carefully studied for multiple reflections between the surface and the shallow Cimarron limestone. No evidence of such events was discernible, despite the fact that excellent single reflections were being obtained from the Cimarron lime on the

majority of records. Holes were drilled to the Cimarron and depths and velocities were measured to this horizon for identification.

Certainly these experiments do not disprove the existence of multiple reflections nor even the existence of surface reflections at locations other than those at which the work was done. The results strongly suggest, however, that multiple reflections involving reflection from the ground-air interface are highly unlikely where the boundary conditions are similar to those existing in the experiments described.

The highly contrasting density and elasticity constants of any earth materials and air would suggest that an interface between these

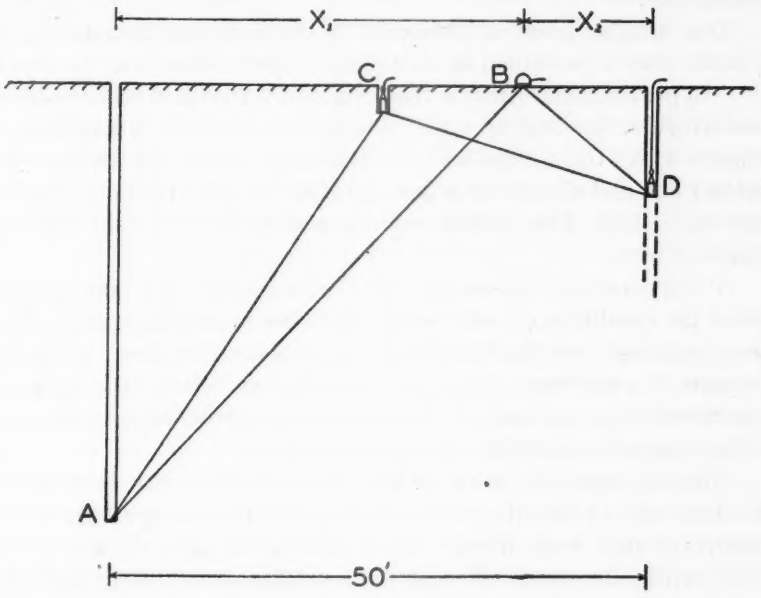

FIG. 1. Diagram of the field setup used in attempting to detect reflections from the surface.

two media should form an excellent reflecting boundary, yet the results of the experiments described suggest that this is not the case. A possible explanation may lie in the fact that the sound-velocity boundary between air and earth materials is not sharp at the surface of the earth. It has been shown that velocities of less than that of sound in air are measurable in very-near-surface earth materials. Though such velocities increase with depth at a rapid rate through the so-called seismic weathered layer, it is not unusual to find that depths of 50 to more than 100 feet are penetrated before encountering unweathered ground velocities approximating 5,000 feet per second.

This velocity range, distributed throughout a substantial thickness of surface materials, would not suggest a sharply defined reflecting interface. However, as the low-velocity weathered thickness approaches zero the velocity interface becomes sharper and the possibility of reflection from the boundary should become greater.

In this connection, an additional report may be of interest. This report, by W. B. Kendall, covers experiments similar to those described above, at two locations in the Beaumont area of the Texas Gulf Coast, in which shot and recording holes of 200-foot depth were used. The results of these experiments were also similar to those previously described; i.e., no positive evidence of surface reflections was discernible.

One notable point of difference in the experiments made in the Coastal area is contained in the following quotations from the report:

"In previous experiments the surface of the ground was considered too irregular for best results . . . with this in mind, a location was chosen where the surface was flat and away from road ditches. This looked like and should have been an ideal location for obtaining surface reflections. The ground was water soaked down to at least two hundred feet."

It appears from this report that the Beaumont area may have fulfilled the condition of weathering thickness approaching zero. However, although mention is made of water saturation down to 200 feet or more it is not clear whether such saturation included the surface or was merely near the surface. For this reason, further experiments in an area of surface saturation might be of interest.

Similar experiments would also be of interest with shot and recording points below the surface of deep water. Although I know of no reports on such work, it may well be that surface reflections have been observed in the course of work done in off-shore or deep-water lake areas.

The reports referred to in this discussion were made available through the courtesy of the Amerada Petroleum Corporation.

NOTES ON MULTIPLE REFLECTIONS*

DEAN WALLING†

Since the inception of the reflection seismograph, apparent reflections have been observed from time to time, which for one reason or another, do not meet the requirements of normal reflections from interfaces in the sedimentary section. Various theories have served to explain and allow the proper interpretation of a large percentage of these spurious energies. Among these is the multiple-reflection theory which has proven to be applicable in many cases.

There now exists irrefutable proof that multiple reflections have been recorded and in my opinion there remains only the question of how frequently they occur throughout the various areas with differing surface and subsurface conditions. While the energy in any multiple reflection is obviously considerably less than in its corresponding simple reflection, there is very little question that multiple-reflection energy in many regions is within the reach of present-day amplifying systems.

Failure to identify multiple reflections as such may at times introduce serious errors in the results, since reflecting horizons at more than twice their actual depths may be computed and utilized. In addition, the slopes of these strata will be computed erroneously. Thus it is possible to map a bed at more than twice its actual depth, and with an apparent slope appreciably greater than its actual slope. If the multiple reflections are interspersed, as they usually are, with other better or equally good simple reflections, no serious adverse effect will be introduced in the final maps. However, in areas of few or poor reflections the occurrence of fair multiple reflections may lead to the erroneous mapping of a deeper bed which is in fact nonexistent, and whose dip might bear no relationship to the dip of the actual bed at that depth.

Fortunately any multiple reflection can be readily identified from an inspection of the cross-section and a study of the normal moveout time of the reflection. In general, a multiple reflection does not persist over as large a span as its corresponding simple reflection. The normal moveout of a multiple reflection (from the surface) is equal to twice that of a simple reflection with half the travel time and half the

* Presented at the Los Angeles meeting of the Society, November 7, 1946. Manuscript received by the Editor February 10, 1947.

† Western Geophysical Company, Los Angeles, California.

spread. This is readily apparent if a sketch is drawn of the paths involved.

Although one should be constantly alert to the possibility of multiple reflections, the evidence to date indicates that these have sufficient energy to be recorded with large amplitudes only under special conditions. As a result they do not affect the interpretation of the vast majority of seismic records in most areas. In any event, since multiple reflections can be identified, their effect can be greatly minimized and in most cases eliminated entirely by proper record and cross-section analysis.

DISCUSSION—MULTIPLE REFLECTIONS*

C. H. DRESBACH†

In various places along the east side of the San Joaquin Valley, roughly thirty miles north of Bakersfield, reflected events have been observed that plotted below the known top of the basement. Sufficient well and velocity data are available to locate them quite closely. From what is known of the character of the basement material, it appears unlikely that the rather smoothly plotting, fairly continuous events could originate from within the basement. The conclusion is therefore forced that they must represent multiple events of some sort.

* Manuscript received by the Editor January 23, 1947.

† Colombian Gulf Oil Co., Bogotá, Colombia.

MULTIPLE REFLECTIONS OF SEISMIC ENERGY*

RAUL F. HANSEN†
Translated and Edited by Curtis H. Johnson‡

ABSTRACT
(by Translator)

This paper is a report of observations of multiple reflections in seismograph work in Argentina, of successful methods of identifying them, and of unsuccessful attempts to eliminate them. The paper begins with generalizations regarding the expectancy of multiples and develops geometrically (using straight-line paths) the relation between multiples and their primary reflections for the cases of multiple reflection between a horizon and the surface and between two horizons, as regards time of reflection, dip and average velocity. The importance of a sharp reflecting contrast at the surface is emphasized, and it is concluded that the base of weathering may be more important in the formation of multiples than the surface of the earth. Early observations of multiple reflections from a volcanic flow and from a shallow basement are described. Other areas showed discordant data on the seismograms and cross sections, which, if due to multiples, could only be caused by multiple reflections from good *sedimentary* reflectors. In these areas a method for identifying both types of multiple reflections by their low average velocity as obtained by shooting reflection velocity-profiles was developed, the work being facilitated by considerable knowledge of velocity and section from previous refraction shooting. Though this reflection velocity-profile method is considered essential to positive and detailed identification of multiples, two methods of multiple identification using ΔT variations in continuous profiling are described and the results of considerable work with one of them are reported in graphical form, showing not only a separation of multiple from real reflections but also the determination of the true velocity-depth function by means of the real reflections so segregated. Experiments are briefly described in which variations in size or depth of shot and variations in filters were *not* effective in reducing the ratio of multiple reflections to real reflections. The paper closes with suggestions for identifying multiple reflections by their abnormal curvatures in discontinuous, symmetrical-spread dip shooting, and for using primitive qualitative methods where the topography or subsurface are not suited to the quantitative methods developed here.

I. INTRODUCTION AND THEORY OF MULTIPLE REFLECTIONS

Since the theory of geometrical optics has provided the solutions for most of the seismic phenomena heretofore observed and is the basis for most of the seismic exploration methods in use today, let us apply this theory to explain the formation of multiple reflections in the transmission of seismic energy. As an example of the application of these principles to determine the characteristics of multiple reflections, let us review the various manifestations of this kind which have been observed in Argentina, and the expriments and theories which have been devised to obtain a better understanding and a better control of this phenomenon.

* *Reflexiones Multiples, Energia Sismica*, Boletin de Informaciones Petroleras (Organo Oficial de Y.P.F.), -R. A., Numero 261, 1946. Manuscript received by the Editor August 11, 1947.

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Before trying to find multiple reflections in seismograph work one is led to expect them, and can predict approximately what their properties will be, from the following two general observations:

1. Just as the phenomena of refraction, reflection, attenuation, filtration, diffusion, etc. have been observed in seismic waves as in other types of wave energy, so other phenomena common to other types of wave energy should also be found in seismic waves—such as diffraction, transverse waves and multiple reflections (like those obtained with two mirrors properly located with respect to the image), etc.

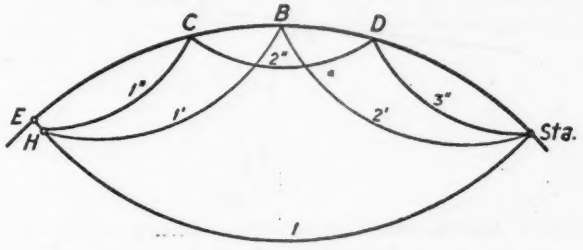


FIG. 1. Refracted seismic waves that have been reflected by the surface of the earth.

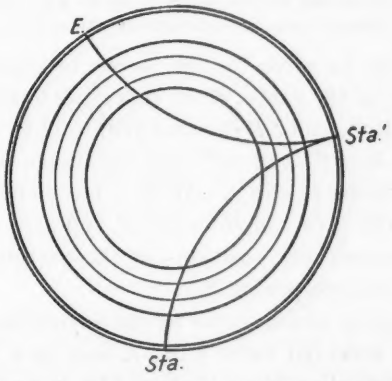


FIG. 2. Reflection of an earthquake wave by the earth's surface.

2. A similar problem is well understood in the study made in general seismology on earthquakes, i.e. the refracted waves which are reflected once or more at the surface of the earth (Figs. 1 and 2). If the similarity of this process to the formation of multiple reflections be debatable, the earthquake process at least indicates the ability of the surface of the earth to reflect a large percentage of the seismic energy reaching it from below.

The following paragraphs explain the two most common types of multiple reflections that may appear on seismograph records: (1) between a reflecting horizon and the surface of the earth (Fig. 3),

and (2) between two reflecting beds (Fig. 4). Though, in the interest of simplicity only these two cases are described, other more complicated cases can probably occur.

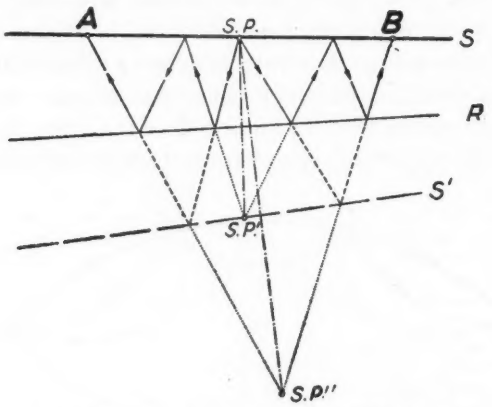


FIG. 3. Multiple reflections between a reflecting horizon and the surface of the earth.

CASE 1. MULTIPLE REFLECTIONS BETWEEN A REFLECTING HORIZON AND THE SURFACE OF THE EARTH

This case is easy to solve by the theory of images. In Figure 3, let S be the surface of the earth, R the reflecting horizon "generating" the multiple reflection, and SP the shot point. Then S' is the image of S with respect to R; SP' and SP'' are the image points of SP with respect to the surfaces R and S'. With these elements it is easy to draw the path of the rays which leave SP and arrive at the points A and B which represent the positions of the extreme receptors of a spread symmetric with respect to SP.

Since the reflection which seems to come from the imaginary horizon S' is actually reflected twice from R and once from S, the data for the apparent reflection from S' should bear the following relation to the data for a single reflection from R: (1) Approximately double the reflection time (if the dip is not too large), and, (2) approximately double the angle of dip; furthermore, (3) since the ray for the reflection from the imaginary bed S' actually always travels through the formations between S and R, it should have an average velocity equal to that in the interval S-R, regardless of the velocity which exists at the depth corresponding to its reflection time.

CASE 2. MULTIPLE REFLECTIONS BETWEEN TWO REFLECTING HORIZONS

This case may also be solved by the theory of images: Let S (Fig. 4) be the surface of the earth and a and b the two reflecting hori-

zons in question. Then $(a\text{-}b)'$ is the image of a with respect to b; SP' is the image of SP with respect to $(a\text{-}b)'$; SP'' is the image of SP with respect to b; and SP''' is the image of SP'' with respect to a.

With these points and surfaces it is easy to trace the paths of the rays which reach A and B from SP. The data for a multiple reflection generated between a and b will delineate the imaginary bed $(a\text{-}b)'$

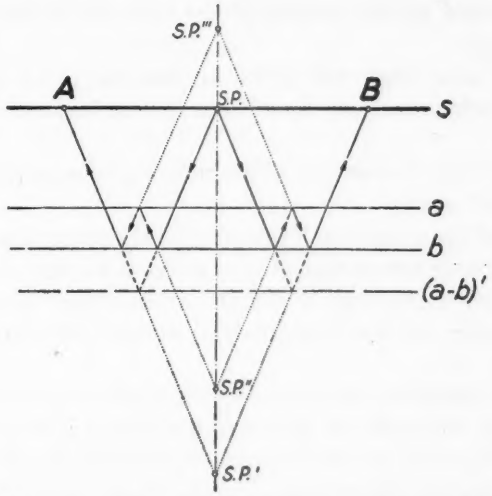


FIG. 4. Multiple reflections between two reflecting beds.

having a reflection time equal to that of the deeper actual reflecting bed, plus the difference in the reflection times of the two actual reflecting beds:

$$T_{(a-b)'} = T_b + (T_b - T_a).$$

Compared with the rays reflected from bed b, the seismic rays corresponding to the multiple reflection travel over an additional path entirely between beds a and b, hence the average velocity between b and the imaginary deeper bed $(a\text{-}b)'$ is the same as in the interval between a and b.

For Case 2 multiple reflections the apparent dip is a complicated function of the dips of its two "generators," but, as worked out above, simple relations between the time and the average velocity of the multiple and of its "generators" may be stated as follows: (3) The time of reflection of a Case 2 multiple reflection is equal to that of the deeper generating bed plus the difference between the reflection times of the two generating beds, and (2) the average velocity in the interval between the deeper generating bed and the multiple is the same as the

average velocity in the interval between the two generating beds.

The above theoretical relations have been obtained without considering the effects of the surface (weathered layer and topography). These effects modify the conditions for multiple reflections, and in practice can never be exactly evaluated. Weathering corrections for multiple reflections are almost impossible to calculate since, to date, there is no concrete evidence to prove whether reflections are returned downward by the surface of the earth or by the base of the weathered layer.

Based on experience and physical reasoning, the following are presented as being necessary conditions for the formation of multiple reflections:

(a) The existence of strata which reflect a large percentage of the incident energy.
(b) Surface conditions such that explosive charges are efficient and that a large percentage of the emergent energy is reflected.
(c) Formations having minimum attenuation and absorption of seismic energy by secondary effects (diffraction, diffusion, etc.).

The most important of these requirements is apparently the second one, since wherever the presence of multiple reflections has been proved (La Dormida on the Pan-American route in the province of Mendoza, Colorado River basin, Salado River basin, etc.), excellent surface conditions have been found, with a good water table at shallow depth giving a thin, uniform well-defined weathered layer.*

Concerning the doubt that exists as to whether multiple reflections of Case 1 represent the image of the earth-air boundary or of the base of the weathered layer, nothing positive may be said at this time, since both surfaces show remarkable contrasts between the elements they separate; nevertheless, the strict relation, existing in all cases proven to date, between the occurrence of multiple reflections and the presence of a uniform, well-defined water-table type weathered layer favors the idea that the base of the weathered layer is the upper reflecting surface for Case 1 multiple reflections.

Moreover, L. D. Leet[1] shows records of the determination of average velocity in a well, on which there was evidence of longitudinal waves reflected from the base of the weathered layer.

As one more piece of data it may be added that in the Salado River basin (where a high percentage of multiple reflections have ap-

* Figure 4a, an outline map of Argentina, has been added by the translator for the benefit of readers of GEOPHYSICS.

[1] *A Plutonic Phase in Seismic Prospecting*, Bull. Seis. Soc. Amer., vol. 27, 97–98, No. 2, 1937.

FIG. 4a. Map of Argentina showing areas where seismic work was done.

peared, and where methods of studying them have made the most progress) in the areas of very good records and corresponding ideal surface conditions, all the deep reflections are multiples of such large energy that they mask the real reflections, whereas, in other parts of this basin, where the surface conditions are less ideal and the records are correspondingly poorer, multiple reflections are less persistent and it is possible to pick some real reflections.

As experience grows it may be possible to obtain new proofs which will settle the theories on the fundamental question of just what constitutes the upper reflector when multiple reflections of Class 1 are obtained.

II. FIRST OBSERVATIONS OF MULTIPLE REFLECTIONS IN ARGENTINA

In the La Dormida area in Mendoza province (Fig. 4a) where much reflection seismograph work has been done, the existence of multiple reflections was verified for the first time. On the records and cross sections of this area there appeared a zone with very little relief and abundant data down to a reflection time of 1.0 or 1.1 seconds, at which time there appeared a very strong reflection (which was shown by later refraction work to correspond to a volcanic flow). The reflections below this level showed very definite dips and, still deeper, the reflections systematically crossed over each other on the cross section. Many of these later reflections appeared with considerable intensity and in what was normally a zone of silence on the seismograms.

The suspicion arose that these deep reflections might be multiples, since it was shown from the relations of the reflection times that some of them were effectively multiples of the volcanic bed of first, second, and up to the third order; i.e., if the time of the reflection from the volcanic bed was 1 second, the multiples mentioned would have times of 2, 3 and 4 seconds, respectively.

This phenomenon did not occur all over the area, but only along one part of the Pan-American Highway which crosses this region and where the surface conditions were extraordinary as regards good transmitting ability and uniform water table corresponding to the base of the weathered layer—as contrasted with the neighboring sand dunes and dry plains.

After making this discovery it was thought that there might be a similar origin for very deep, isolated reflections which had appeared in other regions, and which, up until this time, could not be explained.

Simultaneously with the operations in the La Dormida area, the existence of multiple reflections from the granite basement was noted in the area of the Colorado River (Rio Negro Territory), where the

existence of basement at a shallow depth was already known from refraction work.

At this stage of the development, knowledge of the phenomenon stood as follows:

(a) Methods of detecting multiple reflections were inadequately developed, since in areas where many reflections at all depths were obtained it was very difficult to establish the condition of multiplicity of some reflections from the sole fact of their having approximately double the time of others.

(b) There were no clear ideas of the underlying conditions resulting in the formation of reflections of this kind, since they had been observed only in places where the original reflection corresponded to igneous rocks, and it was believed that this was the determining factor—although the possibility was recognized that a succession of sediments might exist whose physical constants were of great enough contrast to cause the reflection of percentages of energy comparable to those in proven cases of multiple reflections.

III. COLORADO RIVER BASIN

At the beginning of reflection seismograph work in this sedimentary basin, the depth to the basement and the velocity as a function of depth were known from previous refraction shooting.

This is an area of "llano" topography, low with respect to the nearby ocean, and with a shallow water table at depths, in general, 3 to 7 meters below the surface.

The cross sections, obtained from very good seismograms, are usually rich with data at all depths, and the information is very complete.

Two circumstances, neither conclusive, suggested the possibility that multiple reflections might exist. The first of these was that numerous reflections appeared below the known depth of the basement, and while these might have been from discontinuities within the basement complex, they were more probably multiples of upper horizons which were good and continuous. The other circumstance was that on the cross sections, as shown in exaggerated form in Figure 5, there sometimes occurred the following condition: the upper beds nearly horizontal and those below approximately 1.3 seconds with slight but definite dips between which appeared some discordant ones generally having much less dip, approximating that of the upper beds. Even though these discordant reflections might have been caused by internal discontinuities in the strata, there was also a probability that they might be multiples of the upper beds; the fact that they did not have exactly double the time of any particular upper bed could have been

due to the distortion produced by the weathered layer as described hereinabove.

After beginning the work, in order to determine the velocity as a function of depth and to compare it with that calculated by refraction methods, velocity tests by reflection profiles were shot. These were in

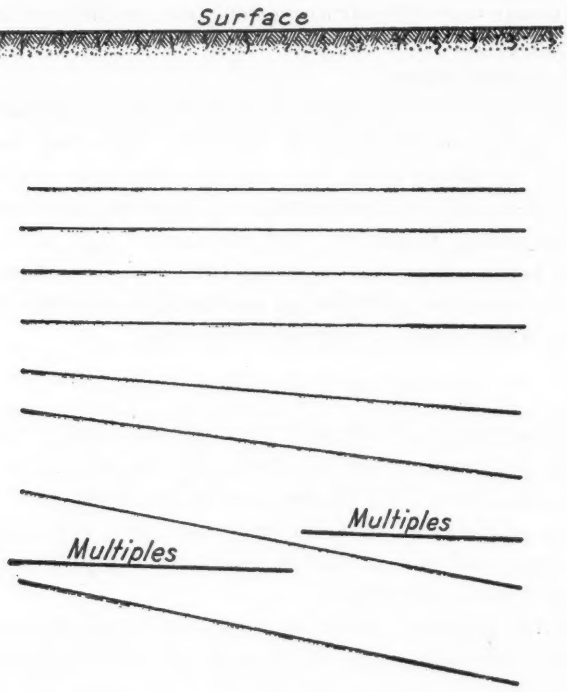


FIG. 5. Cross section showing discordant apparent dips due to multiple reflections.

two locations relatively close together, suitable on account of their good quality of reflections, slightly dipping beds, flat topography and uniform weathered layer.

Of these two tests the second, because the shooting and interpretation was done after more experience with the problem, turned out much the better of the two and gave very interesting results.

The points corresponding to the picked reflections were plotted on a time-depth graph (Fig. 6). Fitting a curve through the points *l*, *a*, *e*, *C*, *K*, *B*, *h*, *g*, *f*, *E*, and *d* in accordance with their positions and weights, a law of velocity is obtained which is very similar to that obtained by refraction shooting, as can be seen in Figure 6, where the two curves have been superimposed. It should also be remarked that in the interpretation of the refraction profile, which was not of good

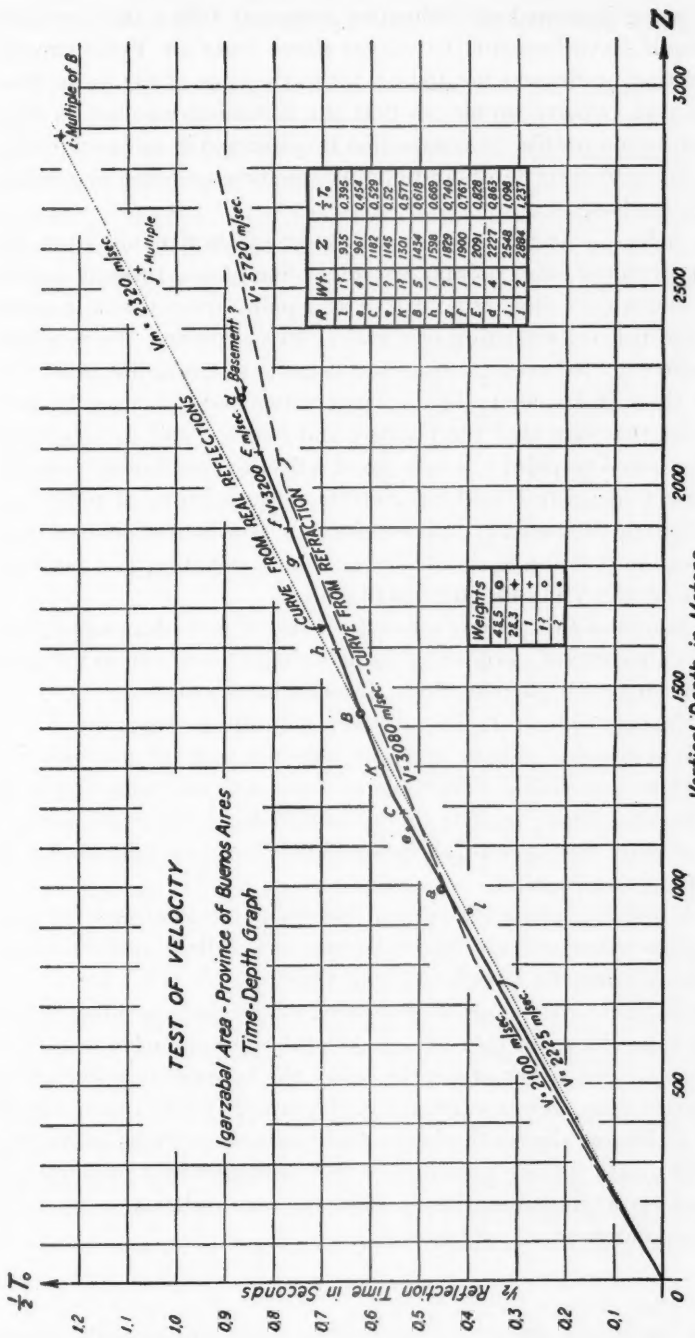


FIG. 6. Reflection time-depth graph, Igarzabal area, Province at Buenos Aires.

quality, some intermediate velocities were not taken into account which would have brought the curves closer together. Furthermore, the refraction profile was located nearer to the edge of the basin than the reflection velocity profile, so that the basement was not as deep at the refraction profile. This assertion is confirmed if we consider the point *d*, because of its depth and quality, as corresponding to a reflection from the basement.

Two points, *i* and *j*, appear which depart noticeably from the curve fitted to the other points. A straight line passed through *i* and *j* and the origin cuts this "true" curve at a point approximately equal to half the time of reflection of *i* and *j*. Remembering the relations that should exist between the time and velocity of a multiple reflection and the time and velocity of its "generating bed," it may be seen clearly and precisely that the points *i* and *j* correspond to reflections of this nature. The point *i*, a very good reflection, is aligned perfectly with respect to point *B* and has exactly twice its time of reflection. Also, although the point *j*, a poor reflection, is a little displaced with respect to the position it should have, it may possibly be a multiple of point *C*, or of an impulse just ahead of *C*.

The results of this project yielded a series of new ideas amplifying previous concepts and permitting the planning of more serious methods of determining multiple reflections. The new ideas were:

(a) Not only igneous rocks can generate multiple reflections.
(b) It is possible to have multiple reflections on the same seismogram originating independently from different reflecting beds.
(c) In areas where velocity increases with depth the surest method of determining multiple reflections is the test for velocity by reflection profiles.
(d) A definite relation is evident between the occurrence of multiple reflections and the existence of excellent surface conditions from the seismic point of view.

In this basin little effort is necessary to eliminate or identify the multiple reflections, for they are, in general, not conducive to serious error. They occur either at depths below the basement or shallower; in the latter case they usually are in the minority and can easily be ignored in tracing the real horizons. Only on some sections containing sparse deep data is there a possibility that multiples may predominate and cause errors in attempting to trace the real horizons on the basis of the preponderance of evidence.

IV. SALADO RIVER BASIN

This basin was discovered by seismic refraction shooting which was distributed so regularly over the area that a great deal was learned

about the depth to basement and the velocities in the stratigraphic column there.

When reflection work to study the structural features in the Salado River basin was begun, experience with multiple reflections had already been acquired in the Colorado River basin, and, since the surface conditions appeared similar in the two areas, it was decided to shoot some reflection velocity profiles in the Salado River basin. Since it immediately became apparent that the time-depth curves would be difficult to interpret, four reflection velocity profiles were shot: one

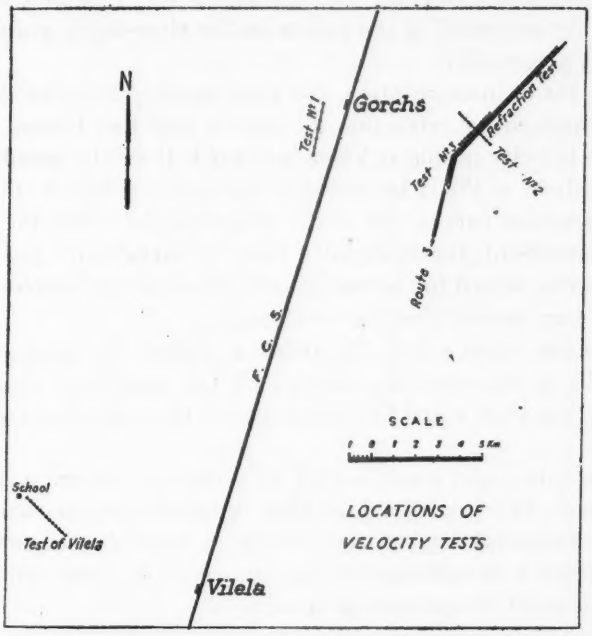


FIG. 7. Map showing location of profiles near Vilela and Gorchs.

north-west of Vilela railroad station, another at Gorchs railroad station and two perpendicular to each other some ten kilometers east of Gorchs (Fig. 7).

Many multiples reflections were evident on the time-depth graphs calculated from these tests. In fact, below a certain depth almost all the reflections were multiples. Thus, since so very few real deep reflections appeared, the true velocity curves could not be determined at depth. In order to have sufficient points on the time-depth graphs, the observations were finally interpreted in the following, manner:

(a) The test at Vilela was interpreted independently because the thin sedimentary section there would not logically permit combining it with the tests at Gorchs where the section was thicker.

(b) The points calculated from the three velocity profiles at Gorchs were plotted on the same time-depth graph to increase the probable accuracy of the fitted curves.

Reflection velocity profile at Vilela.—(Fig. 8.) The depth to basement at this location is of the order of 3,100 meters, a value obtained by interpolation, since there was no refraction profile sufficiently nearby to use its data directly.

The seismograms of the Vilela profile are excellent, containing a great deal of data and quite a few reflections which could be picked at large horizontal distances from the shot point. This gave results of good quality and most of the points on the time-depth graph are located very accurately.

As an aid to interpretation, the time-depth graph also shows the curves, obtained by refraction at Gorchs and Las Flores, between which the velocity profile at Vilela is located. It will be noted that the curve obtained at Vilela by fitting to the better points is comparable to the refraction curves. All of the reflections to which the curve is fitted are excellent, the reflection *a* being of particularly good quality since it can be picked to the maximum horizontal displacement and its points line up perfectly on the x^2-T^2 graph.

At greater depths than the point *a* (except the points *r* and *s*, which will be discussed separately) all the additional points have velocities less than *a* and fall decidedly off the refraction time-depth curve.

The points *r* and *s* are located very near to the refraction time-depth curve, but the reflections they represent appear sharply only at some horizontal displacements while at other displacements they are interfered with and even hidden completely by other reflections of greater moveout (lower average velocity).

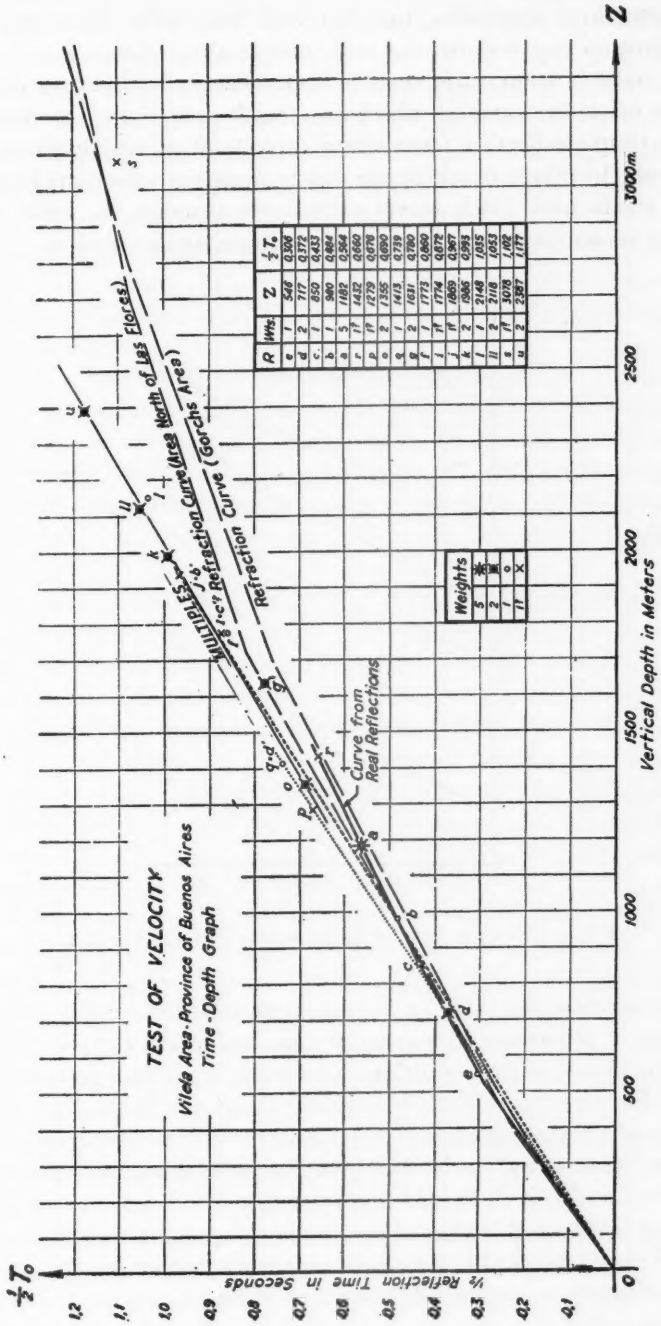
These interferences can sometimes be resolved, and the reflections which cause them determined, as indicated schematically in Figure 9.

Returning to Figure 8, if the interpretation is made without considering the idea of multiples the following anomalies will be noted:

(1) Interval velocities appear which might be called negative, having no physical explanation. (Examples: lines joining *u* with *s*, and *r* with *p* or *o*.)

(2) As a consequence of the above anomaly it is observed that reflections, or their corresponding points, which appear in a certain order in time appear in an inverted order in depth.

(3) Lines joining successive points exist whose slopes indicate velocities so low that they cannot be justified in view of the velocities in beds immediately above and below.



R	Wts.	Z	½ To
e	1	548	0.306
d	2	717	0.372
c	1	859	0.433
b	1	980	0.484
a	5	1102	0.544
r	11	1432	0.660
p	11	1279	0.616
o	2	1355	0.690
q	1	1413	0.739
g	2	1631	0.780
f	1	1713	0.860
j	11	1774	0.872
k	2	1869	0.907
l	1	2148	0.993
m	2	2108	1.053
s	1	2109	1.092
u	2	2387	1.177

FIG. 8. Reflection time-depth graph, Vilela area.

These three anomalies, together with the visible interference of reflections on the seismograms and cross sections obtained in routine work, make it seem quite certain that reflections from two distinct sources exist: (a) some of which are "real" reflections, i.e. resulting from a simple reflection from strata capable of returning seismic energy and, (b) others of which are due to multiple reflections from the upper strata and which travel exclusively through the beds whose average velocities are on the order of 2,000 meters per second.

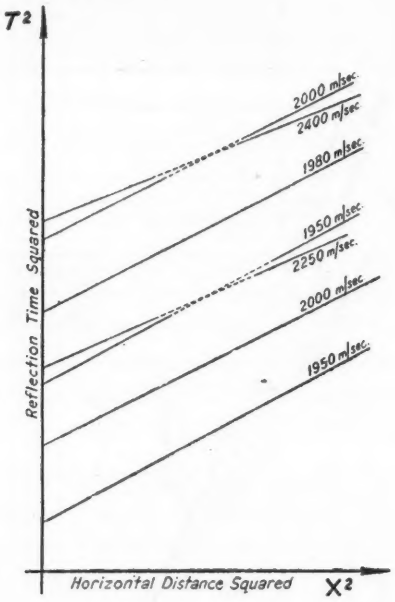


FIG. 9. Graphs of T^2 vs. x^2 for reflections shown in Figure 8.

The noteworthy thing in all the work reported here is the great quantity of reflections of this latter type which are created. In some cases, by means of the conditions (described in the first section of this paper) for multiple reflections between a bed and the earth's surface (or base of weathering), it is even possible to determine uniquely which are the "generating" beds. Thus, in Figure 8, it may be determined that q is a multiple of d, j of b and i possibly of c. This is because each multiple (such as q) is aligned on the time-depth graph with its "generator" (such as d) and the origin of graphical coordinates, and has approximately twice the reflection time of its "generator." The other multiple reflections, such as p, o, f, k, l, ll, and u, should be similarly related to upper real reflections which were not picked.

Reflection velocity profiles at Gorchs.—In this area very interesting results were expected since from refraction data a very complete and well-mapped sedimentary series was available as a standard of comparison. However, after shooting the first test (Fig. 7), it was found that the seismograms were of poor quality and it was deemed advisable to shoot two additional tests perpendicular to each other (2 and 3, Fig. 7) to check the first one.

The general character of the Gorchs tests, including the anomalies on the seismograms and on the time-depth graph, was the same as already described for the test at Vilela, except that there was a greater thickness of sediments at Gorchs.

In the Gorchs tests all the available reflections were picked, even those of low quality and those which only appeared in fragmentary form, in the hope of learning something by means of a system of probability applied to a mass of data on the time-depth graph. To provide additional values for such an analytical procedure, all the points calculated from the three velocity-profiles were plotted on a single time-depth graph (Fig. 10).

By picking and weighting all possible reflections according to uniform criteria and then treating all these weighted points on the time-depth graph in a statistical manner without returning to hunt for additional reflections to fit any particular curve, a conscientious attempt was made to avoid misleading wishful thinking.

In a first analysis it can be seen that there is not a random dispersion of points, but that there are coincidences, or at least decided groupings of points obtained from the three tests. Therefore, well-defined clusters of points appear which include some points obtained from all three tests and, for convenience of discussion, these clusters have been enclosed in dotted squares on the time-depth graph of Figure 10. Since this diagram was to be studied on the basis of probability it was decided to treat each cluster as a single point to give added weight to any conclusions which might be drawn. As a matter of fact, it is highly probable that the points in any given cluster correspond to the same horizon which produces reflections picked in all three tests, sometimes with a difference of one wave length.

These clusters include a high percentage of the total points in the diagram, and the majority of them include points from each of the three tests.

Treating the diagram in the manner explained, it will be observed that for times less than 0.5 second, the clusters labelled *A*, *B*, *D*, and *G* each contain numerous good-quality points. These clusters are near the refraction curve of the place. Beginning at 0.5 second (1.0 second reflection time) clusters and isolated points may be observed

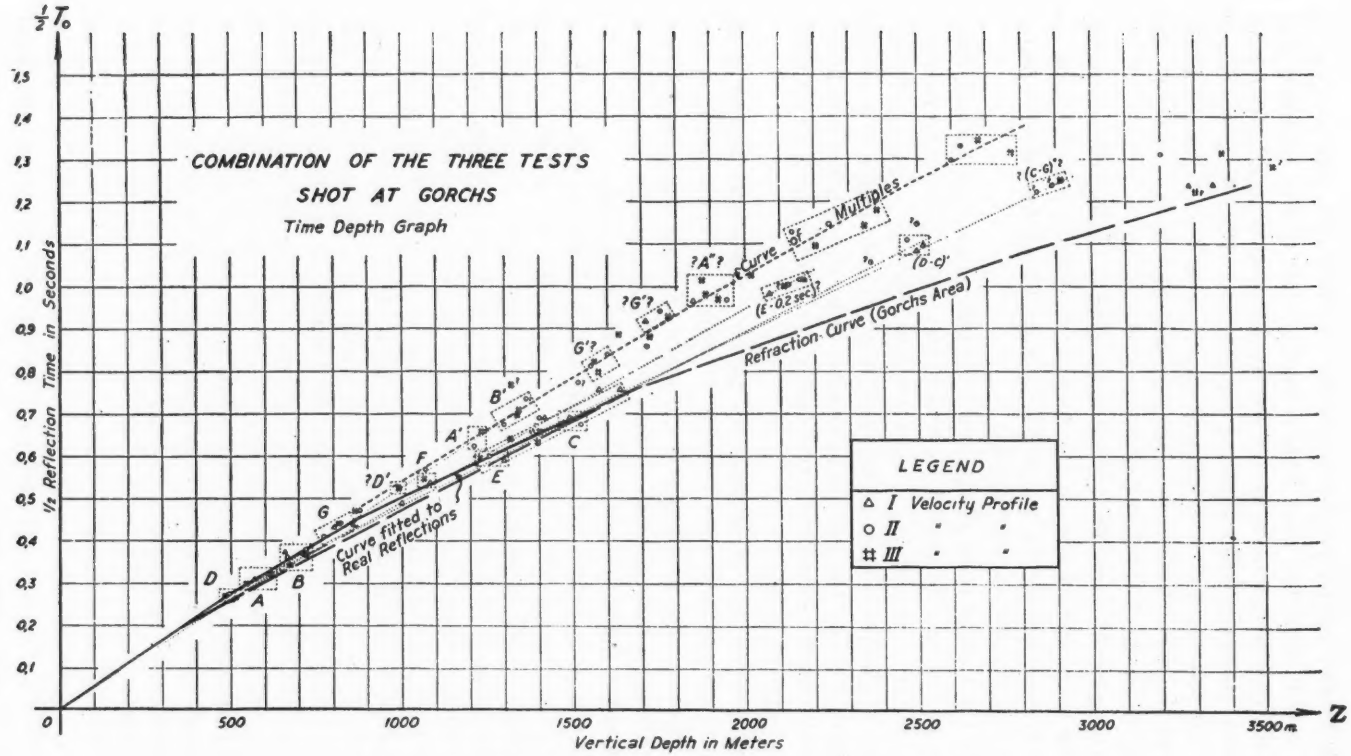


FIG. 10. Combined time-depth data for three tests shot at Gorchs.

which can be arranged according to three different curve branches:

(a) The clusters *F*, *E* and *C* and some isolated points are situated in the neighborhood of the refraction curve. Based on these, and on the clusters occurring before 0.5 second, a time-depth curve has been fitted that, because of its similarity to the refraction curve, is assumed to be the true one. The curve has not been drawn to greater depths since the information is scarce, of poorer quality, and, therefore, more scattered. (This scattering may also be caused by the decrease in accuracy of the method as the depth increases.)

(b) The clusters *D'*, *A'*, *A''* and others not named, together with some isolated points, are arranged on a line of low velocity which has been interpreted approximately by the "Curve of Multiples" that appears in the diagram with a maximum slope corresponding to a velocity of 2,000 meters per second. It has been possible to identify some of these clusters as pertaining to multiple reflections of other interpreted clusters whose letters (with a prime added) have been used to label the multiple clusters. This identification has been made bearing in mind the conditions that a multiple reflection between a layer and the surface of the earth (or a base of weathering) should fulfill as was shown in Section I. Thus the cluster *A'* is a multiple of the first order of *A*, *B'* of *B*, *D'* doubtfully of *D*, and the two *G*'s of different points within *G*, also doubtful. Cluster *A''* has possibilities of being a multiple of second order with respect to *A*. (Triple the reflection time of *A*, and aligned with it and the origin.)

Therefore, it is logical to think that the clusters and points grouped around the curve of low velocity, even those whose "generators" it has not been possible to identify, would belong to multiple reflections of first and second order between reflective layers and the surface.

(c) There exist other clusters, the points within them being too consistent to be attributed to errors of interpretation, that fall off the curve of low velocity and the refraction curve. It seems probable that these may belong to multiple reflections between two layers.

Remembering the conditions pointed out in the first section for this type of reflection with respect to its time of reflection and its mean velocity (that on a time-depth diagram the two "generating" clusters and the multiple should be aligned), we see that the cluster labelled (*D-C*)' fulfills them sufficiently close with respect to the layers represented by clusters *D* and *C*. Likewise, the one labelled (*E*-0.2 sec.)' fulfills the conditions with respect to the layer pertaining to cluster *E* and one that could be at 0.2 second (0.4 second reflection time) that could not be picked on these profiles, though on numerous seismograms in routine work strong reflections that are difficult to

pick only because of their exaggerated curvature can be seen at about this time.

The cluster $(C\text{-}G)''$ is aligned with clusters C and G and its reflection time is approximately equal to $T_c+2\ (T_c-T_g)$. Therefore, it could be a multiple reflection between layers C and G, but of second order.

It might be assumed that a curve determined by these three clusters and other isolated points represented the true curve, but that would imply an illogical relation between clusters C and $(E\text{-}0.2$ sec.$)'$ as it would give an interval velocity of 1,800 meters per second (in a thickness of 600 meters) which is of the order of the velocity directly below the weathered layer. Since the interval velocities each side of this 600 meter thickness are 2,700 m/sec and 3,300 m/sec, it is exceedingly improbable that the 1,800 m/sec value could be correct. Therefore, the more probable explanation is that some of these are multiple reflections of a more complex type than generally appears, although it is not certain that this explanation is entirely correct.

V. EXPERIMENTS AND METHODS APPLIED

Convinced, after these tests, that most of the deep reflections in the basin of the Salado River are multiples of better quality than the real reflections, the possibility of eliminating them was investigated so as to be able to study the structure of the deep strata, which the multiples ordinarily prevent. Several recording tests were made for that purpose, the depth of shot varying to a maximum of 70 meters and the amount of explosives varying between 1 and 20 kilograms. To these different conditions was added the use of various filters in the equipment, without obtaining in any case a change in the relative number and quality of multiples observed as the size of shot, depth of shot, or filter setting was changed.

Nevertheless, these results must not be considered conclusive, as the filters in the equipment used were not sufficiently selective for a test of this kind, and even if they had been adequate, the results should be taken only as applying to the particular area and incapable of supporting a generalized conclusion.

Since varying filter settings and depth and size of shot apparently were ineffective in reducing multiple energy, it was decided at least to develop a method of distinguishing real reflections from multiple reflections in routine work as an aid to the interpretation of deep structure. Actually, the routine method described below was applied in this area more to determine its ability to classify multiple reflections than in the hope of determining deep structure since, from the velocity

profiles already described, it was known that very few real reflections occurred at great depths in this area.

Analytical routine method.—Beginning with the assumption that the multiple reflections and the single, or "real" reflections have different average velocities for the same reflection time (which is learned from the preceding sections) and observing in the approximate formula (derived in Fig. 11)

$$\Delta T = x^2/2TV^2 \qquad (1)$$

how that fact affects ΔT, one can see the possibility of determining whether a reflection is single or multiple when the true law of velocity and the law governing multiple reflections are known.

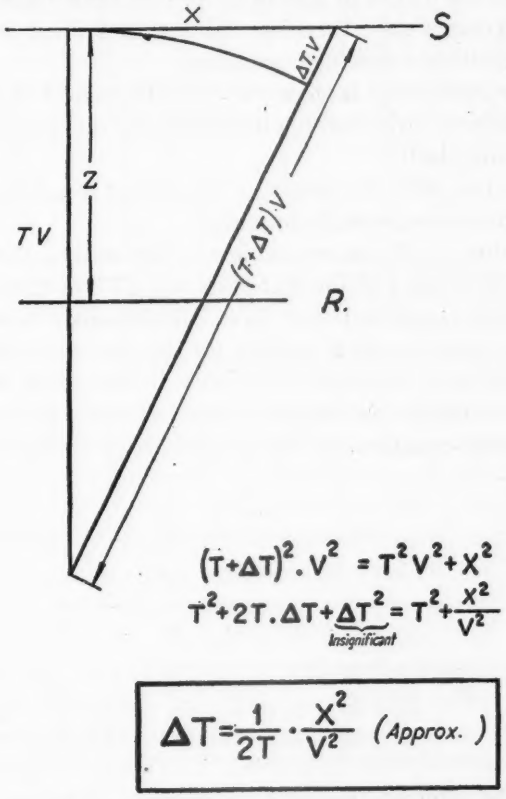


FIG. 11. Derivation of method for recognizing multiple reflections.

If we call the mean velocity of the multiple reflection V_m, and of the real reflection V_r, both appearing at the reflection time T_1, the difference between the values of ΔT of the two reflections will be:

$$\Delta T_m - \Delta T_r = (x^2/2T_1)(V_r^2 - V_m^2)/(V_r^2V_m^2). \qquad (2)$$

In order for the method to correctly classify the nature of the reflection being analyzed, the difference $\Delta T_m - \Delta T_r$ should be as great as possible, and each ΔT value should be large enough not to be seriously affected by the errors that always show up in seismic work.

Analyzing the difference factor on the right-hand side of equation (2) and noting that for a first-order multiple V_m is equal to the value of V_r at the time $T_1/2$, we see that the more rapidly the real velocity increases with depth the more suitable is the area for the application of this principle. In short, in areas where the velocity is constant with depth, the method is not effective.

The only parameter available to make the value of the difference of ΔT vary is the length of spread x. As this value increases, the ΔT difference increases also; therefore the length x must be selected so that it will fulfill the following conditions:

(a) To be sufficiently large so that the differences in ΔT are clear.

(b) Not to be so large that it will deprive the reflections of clearness by excessive angularity.

(c) To agree with the length of the receptor cables with which seismic equipment is generally provided.

As the cable which was available was 800 meters, that length was adopted for the tests, and for that value the ΔT's of real and multiple reflections were calculated. For these calculations a velocity law for the multiple reflections and another for the real were adopted which were composites of the tests of velocity in the basin of the Salado River, aided at the greater depths by the refraction time-depth curve.

By applying equation (1) the results given in Table 1 were obtained:

TABLE 1

Reflection time (*sec.*)	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3
ΔT_m (*sec.* $\times 10^{-3}$)	72	61	53	48	45	43	41	39	37	35	33
ΔT_r (*sec.* $\times 10^{-3}$)	53	47 to 45	44 to 30	38 to 35	34 to 31	30 to 27	27 to 25	25 to 23	23 to 21	21 to 19	19 to 17

As may be inferred from the comparison of values in Table 1, ΔT_m and ΔT_r may be clearly differentiated, and therefore, for this area the spread length of 800 meters is suitable.

The method is applied by continuous profile, as shown in Figure 12. In its application complete lines were recorded which demonstrated the applicability of the method, since the ΔT' s verified with sufficient accuracy the values of the table. Working with this method, depth and

size of shot, settings of filters, etc., also were varied for the purpose of reducing the percentage of multiple reflections, but without concrete success.

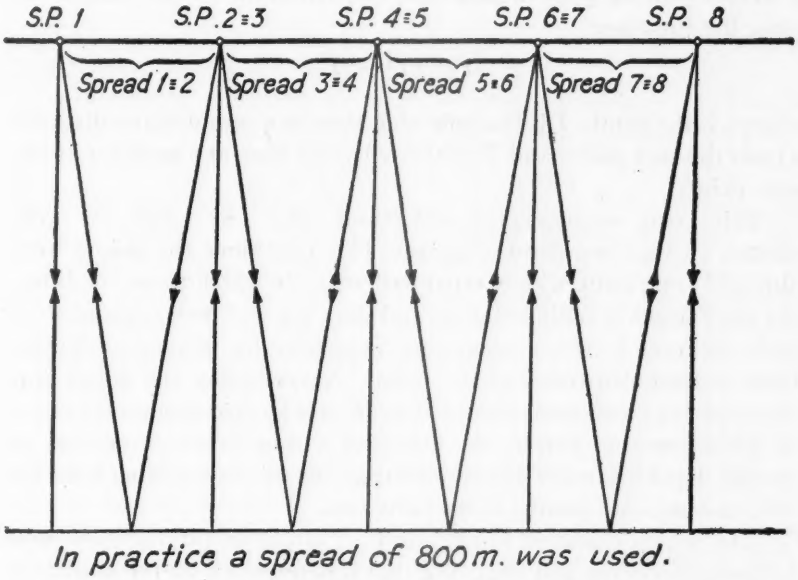


FIG. 12. Arrangement of spreads for continuous profiling.

On the cross sections of the lines shot in this manner, a number of true deep reflections were obtained, though as was anticpated, they were insufficient to define the structure at the deeper levels. However, this lack of deep reflections is simply characteristic of the area, and in no way indicates that the method is not effective; on the contrary, the application of this routine method has proved its efficiency in determining whether the apparent deep reflections were real or multiple.

One thing which has been possible to observe during the application of this method, is that the percentage of multiple reflections depends to a great extent on the surface characteristics along the spread; in the best recordings the appearance of true deep reflections has been practically nil, while where the quality of the record decreases, the number of real reflections at depth is increased. This is a new affirmation of the importance of surface conditions in the formation of multiple reflections.

In the interpretation of the seismograms obtained in this work, the reflections were classified in the following manner: multiple (*M*) real (*R*), doubtful real (*R*?), doubtful (?) and doubtful multiple

(*M*?), in accordance with the comparison of their ΔT's with those which appear in the table. In order to make a further test of the efficiency of the method and to learn something more about the true law of velocity of the area, depths were calculated for all the reflections, using the equation:

$$z = xT_0/2(T^2 - T_0^2)^{1/2} \qquad (2a)$$

where z is the depth, T is the reflection time at a receptor at a distance x from the shot point, and T_0 is the reflection time at a receptor at the shot point.

This being accomplished, reflections (*R*), (*R*?) and (?) were plotted on the time-depth diagram (Fig. 13). Since the points were obtained from quite widely separated areas, in which there are different thicknesses of sedimentation, and since the 800-meter spread gives little accuracy in the z calculation, especially for increasing depths, there is some dispersion of the points. Nevertheless, the points corresponding to reflections classified as (*R*) are located around the curve of refraction, and permit the fitting of a time-depth curve that at greater depths is better determined than the curves resulting from the reflection velocity profiles in the same area.

The points classified as (*R*?) and (?) fall in an intermediate zone between this curve and the curve that is determined by the multiples. The clusters, such as (*D-C*)′, of Gorchs' tests of velocity, that were classified in Figure 10 as multiples between two layers, have been placed on the diagram of Figure 13 and fall within this same zone. Therefore it could be assumed that the deep reflections whose ΔT's are intermediate between the true and the multiple curves in Figure 13 may also be classified as multiples between two layers.

The multiple reflections between various horizons and the surface of the earth—classified as (*M*) and (*M*?)—were not plotted in Figure 13 because they are very numerous and lack practical interest, and only the curve along which they lie has been drawn.

Figure 13 is very significant not only as it relates to the efficiency of the routine method of identifying multiples, but also as it relates to the determination of the true law of velocity.

Another analytical routine method.—As was previously mentioned when Equation (2) was discussed, the discriminating power of the method depends on the true law of velocity, since the less the velocity increases as a function of depth the less will be the difference between V_r and V_m and, therefore, between ΔT_m and ΔT_r. In case the velocity increase is insufficient to permit clear ΔT differences to be obtained with the length of cable available, the method outlined in Figure 14 may be used.

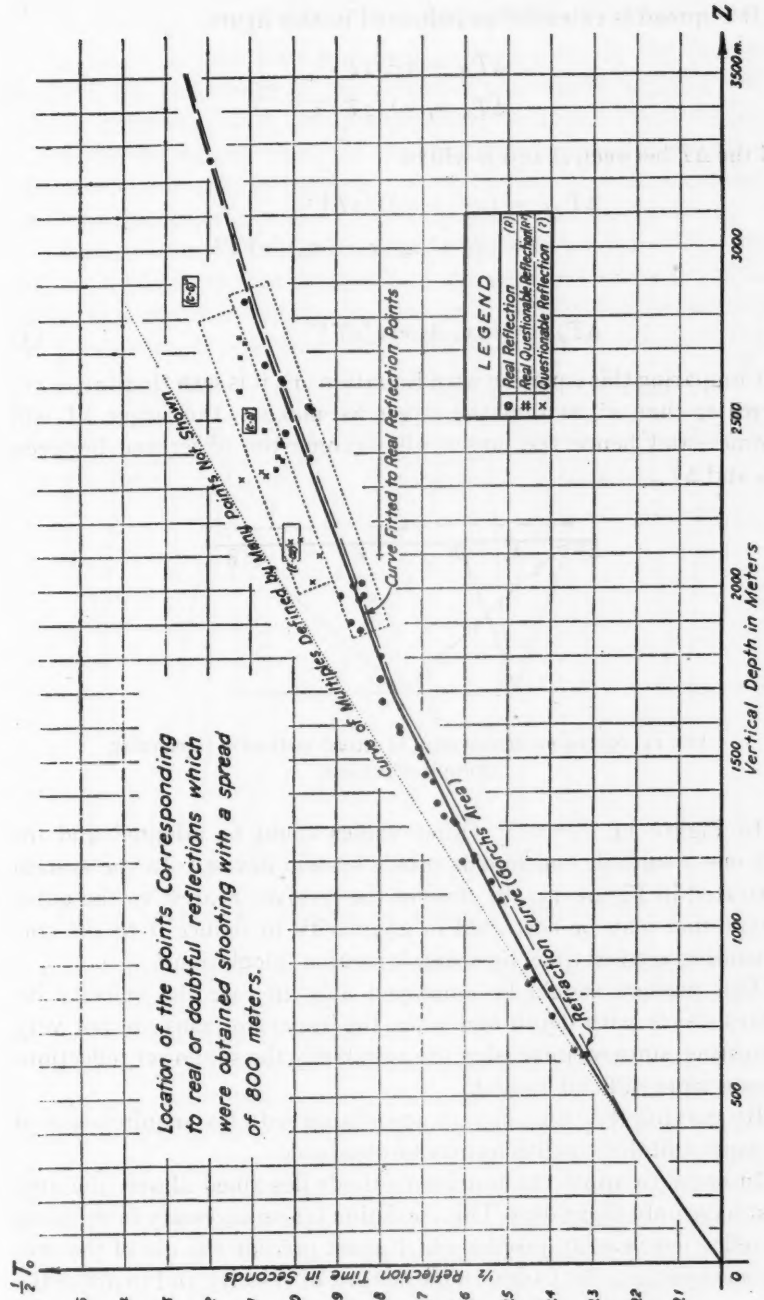


FIG. 13. Composite time-depth graph of reflections from continuous profiling.

If a spread is extended as indicated in this figure,

$$\Delta T_B = x_2^2/2TV^2,$$
$$\Delta T_A = x_1^1/2TV^2,$$

and the ΔT between A and B will be

$$\Delta T_{AB} = (x_2^2 - x_1^2)/2TV^2$$
$$= (x_1 + x_2)(x_2 - x_1)/2TV^2;$$

or

$$\Delta T_{AB} = (2x_1 + x)x/2TV^2. \tag{3}$$

Comparing this equation with Equation (1), it is seen that $(2x_1+x)x$ is greater than x^2, so that the larger we make x_1 the larger ΔT will become—and hence the larger will become the difference between ΔT_m and ΔT_r.

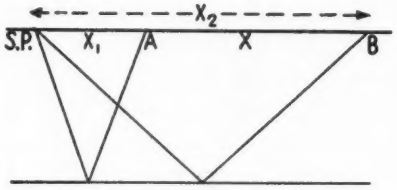


FIG. 14. Spread for employment of second method of recognizing multiple reflections.

In Figure 14, $x_1 = x/2$. Other values could be adopted and for each one a suitable continuous profile system devised. In the system illustrated in Figure 15, the time of the receiver nearest to the point of explosion may be corrected in angularity to reduce it to the corresponding vertical time, by a simple routine calculation.*

This method should be employed only in case the velocity increases slowly with depth and when the upper horizons are not very interesting, since on increasing the angularity the shallower reflections become more difficult to pick.

By varying the value of x_1 in accordance with the requirements of the work, suitable conditions may be obtained.

In order to apply the routine methods described above, the area must have only slight dips. This condition is also necessary in shooting the reflection velocity-profiles which must precede the use of the routine methods in order to determine the law of velocity and to prove the existence of multiple reflections.

* In calculating depths, dips, time ties, etc.—TRANSLATOR.

VI. OTHER CONSIDERATIONS

As may be seen from the explanations given in the preceding sections, the knowledge of the problems concerning multiple reflections is quite advanced, and the necessary solutions have progressed sufficiently to handle many of the multiple-reflection problems encountered—but only in the areas where the topographical and structural conditions permit tests of velocity with reflection profiles.

In areas where it is feasible and desirable to work by "dip shooting" with discontinuous symmetrical spreads, and where it has been shown by reflection velocity-profiles that multiples exist, a routine check as to which reflections are multiples in day-to-day work might

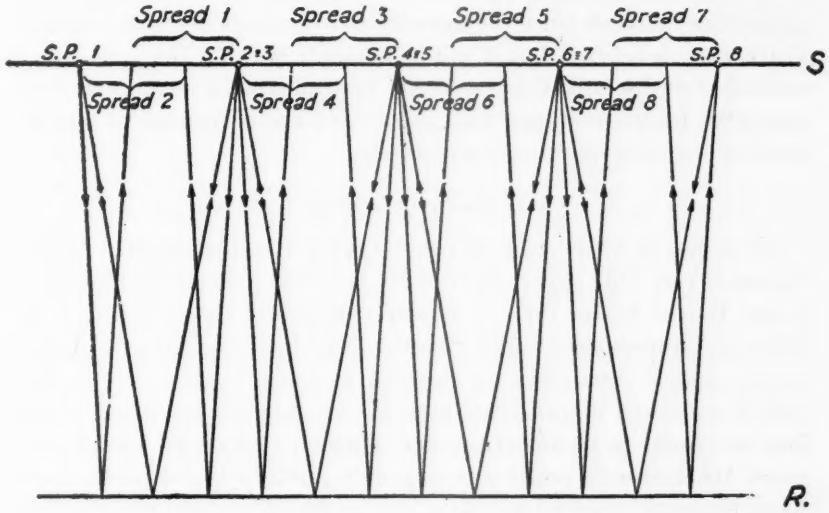


FIG. 15. Arrangement for continuous profiling when second method is used.

be accomplished by increasing the spread length and observing whether the curvature of the wave fronts corresponds to the velocity of multiples or the velocity of real reflections.

Even if reflection velocity profiles cannot be shot to prove the presence of multiples, a comparison of wave-front curvatures obtained in routine work with the curvatures calculated from the velocity obtained by shooting in a nearby deep well might be used to determine whether the reflection being analyzed is real or multiple.

Now, where conditions are not favorable for the determination of multiples by any of the methods described in this report (where, for example, short spreads are required by rolling topography or discontinuous reflecting horizons, or where nothing is known or can be ascertained regarding the true law of velocity) the experience acquired

to date shows that the appearance of multiple reflections is less probable. Nevertheless, as past experiences have shown, under these circumstances an analysis can be made by studying the seismograms and profiles, searching for relations between reflection times and between dips of the reflections, observing the intercrossing of data on the cross sections, etc. Many different cases can be presented, and in each one of them the geophysicist should investigate for possible multiples with the proper discrimination, although it is only fair to admit that for most cases other than those treated in the preceding sections, the analytical and interpretive possibilities are poorer, permitting, perhaps a general qualitative investigation, but not a definitive one.

No experiments have been made to test the effectiveness of these qualitative methods since the quantitative methods described hereinabove were developed, but it will be remembered that the qualitative methods first disclosed the presence of multiples in the days when they were little understood, and may yet serve a useful purpose in supplementing the more quantitative methods.

TRANSLATOR'S NOTE

It should be made clear that this is not a literal translation of Mr. Hansen's very able paper. First of all, it is well understood that even in the United States there is a wide variance in the terms used by different geophysicists to describe the same instruments, procedures, or phenomena. Secondly, the Spanish language is excessively polite and flowery, and if translated literally into English the paper might lose its appeal to technical readers. Thirdly, it must be agreed that when Mr. Hansen's paper was originally published, and particularly when the work reported was done, few geophysicists and fewer executives reacted favorably to the idea that multiple reflections could be of any practical importance in seismograph exploration; hence the paper in Spanish has a slightly defensive tone which the translator has attempted to eliminate as inappropriate in a paper of this importance.

The translator is particularly sympathetic to this paper, since he has observed the same phenomena in California and has used the reflection velocity-profile method of identifying multiple reflections on many occasions, as well as the qualitative methods described by Mr. Hansen. He is in complete agreement with Mr. Hansen's interpretations and conclusions as regards the multiple reflections described in this paper, and can only wish that Mr. Hansen had included a more complete description of his methods of shooting the reflection-velocity profiles, of picking, computing and plotting the reflections on the $x^2 - T^2$ diagram and of correcting, if necessary, for the effects

of curved path and for the effects of picking a phase of reflection later than the actual onset of the wave. These corrections might influence the relative velocity calculated for the multiple and the real reflections and certainly would affect the absolute velocities so that a direct comparison of the velocity from reflection velocity profiles with refraction or well velocities might not be justified.

In conclusion, the translator is happy to have had a part in bringing this important paper to the attention of geophysicists in this country, and hopes Mr. Hansen and the Y. P.F. will excuse any errors of translation of meaning that may have occurred.

PRELIMINARY RESULTS OF A STUDY OF SEISMOGRAPH SENSITIVITY REQUIREMENTS*

P. E. HAGGERTY† AND R. W. OLSON†

ABSTRACT

The ambient ground-noise level is one of the most important factors in determining sensitivity requirements for a seismograph system. This paper, on the basis of eighty-one measurements in three areas in Texas, concludes that for these areas minimum ambient noise levels (in terms of particle velocity) of the order of 3 to 5 millionths of an inch per second are common. Assuming a seismometer sensitivity of 2 volts per inch per second and an oscillograph sensitivity of 5 inches per volt, an overall gain of 20,000 from the output of the seismometer to the input of the oscillograph would be required to give a one-half-inch peak-to-peak deflection from a noise signal with a peak-to-peak particle velocity of 2½ millionths of an inch per second.

INTRODUCTION

There are many factors which influence the sensitivity requirements of a set of operating seismograph equipment. Among the most important is the level of background noise present in the area in which the equipment is being operated. As in radio communication, it is always necessary in the operation of seismograph equipment that the signal being detected in the form of a reflection or refraction be clearly identifiable either through or above the noise background. Accordingly, it would appear of importance that data be available as to the common background levels likely to be expected in actual field operations. Practically it is desirable that these background measurements be obtained in terms of particle velocity inasmuch as the seismometers commonly used are velocity-measuring devices. By particle velocity is meant not the actual transmission speed of the seismic wave but the velocities attained by the particles of earth directly beneath the seismometer.

PROCEDURES USED IN MEASURING PARTICLE VELOCITY

Figure 1 portrays the setup used in measuring the particle velocities. The seismometer was a normal standard-calibrated permanent-magnet dynamic type. The seismometer was, for the tests outlined, seated firmly on the ground surface 200 feet from the amplifier station. The measuring equipment itself was divided into four major com-

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† Geophysical Service Inc., Dallas, Texas.

ponents: the pre-amplifier and calibration circuit, the main amplifier including filters and gain control, a recording string oscillograph, and a calibrated oscillator and meter. The over-all amplifier system had a maximum gain of 115,000 from the output of the seismometer to the input of the string oscillograph. The entire system was substantially flat from 16 to 200 cycles per second with marked attenuation below

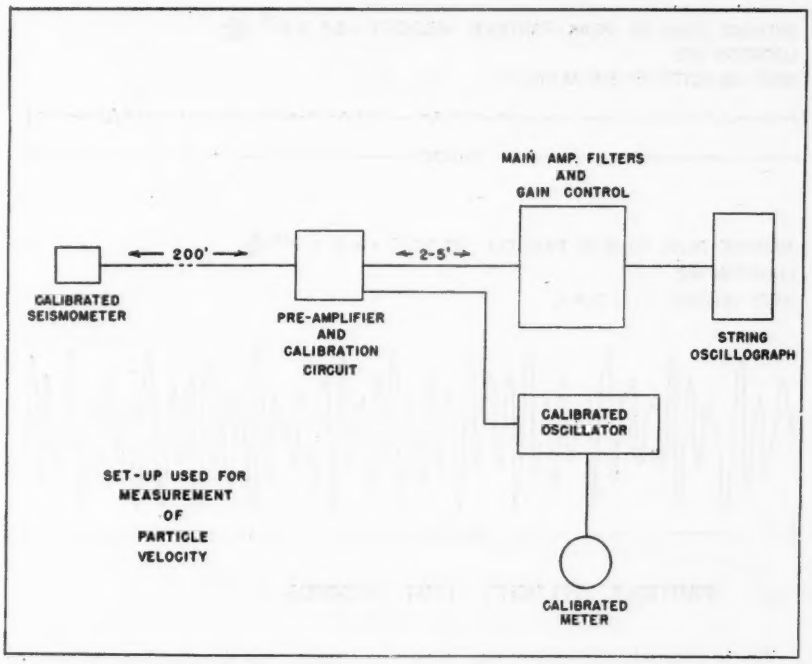

FIG. 1. Equipment setup used to measure ambient ground noise in terms of particle velocity. The seismometer was positioned 200 feet from the amplifier to minimize effects of personnel and equipment on ambient noise level.

16 and above 200 cycles. The gain control allowed control of the amplifier over a range of one million to one in steps of two to one. Wind-velocity readings were based on a K. & E. 0 to 2,000 feet-per-second anemometer which gives average wind velocities. A calibration signal was injected into the amplifier each time a record was made. Several hundred readings in all were taken, but for the purpose of this discussion, only eighty-one of the readings were utilized. The balance included additional variables which cannot be analyzed until more data have been collected. The readings used were made at three different locations—two in Dallas County, Texas, and one in Collin County, Texas.

RESULTS OF THE INVESTIGATION

Figure 2 reproduces two typical records obtained in Area No. 2 in Dallas County. The upper record is typical of the lower particle velocities measured and the lower record is illustrative of the higher particle velocities obtained. It will be noted that the wind velocity during the first test was $3\frac{1}{2}$ miles per hour, and during the second test

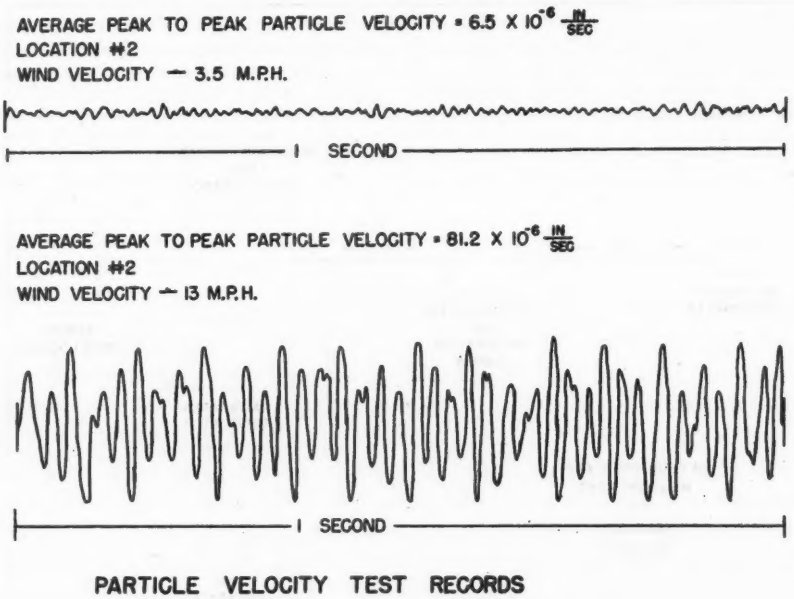
AVERAGE PEAK TO PEAK PARTICLE VELOCITY = 6.5 X 10⁻⁶ IN/SEC
LOCATION #2
WIND VELOCITY — 3.5 M.P.H.
1 SECOND
AVERAGE PEAK TO PEAK PARTICLE VELOCITY = 81.2 X 10⁻⁶ IN/SEC
LOCATION #2
WIND VELOCITY — 13 M.P.H.
1 SECOND
PARTICLE VELOCITY TEST RECORDS

FIG. 2. Reproduction of two typical particle-velocity test records. The top record is representative of the lower particle velocities measured, and the bottom record is representative of the higher particle velocities measured.

was 13 miles per hour. All of the data selected are based on wind velocities of 15 miles per hour or less. This limit was chosen as a rough approximation of the maximum wind velocity allowing continued operation in the field at high instrument sensitivities and without special measures. It will be noted that the upper record shows an average peak-to-peak velocity of 6.5 millionths of an inch per second, and the lower record shows approximately 13 times as high a velocity at 81 millionths of an inch per second.

In Figure 3 the eighty-one tests are plotted in terms of the frequency of occurrence of the various velocities at all three locations. It will be noted that there is a definite peaking at approximately 7 millionths of an inch per second with nearly one-third of the velocities observed at approximately this value. The remaining tests scale on

down in frequency of occurrence and on up to a maximum particle velocity of over 90 millionths of an inch per second. This information would certainly indicate that the seismic system should have sufficient sensitivity to handle background noise levels in the neighborhood of only a few millionths of an inch per second in that for approximately

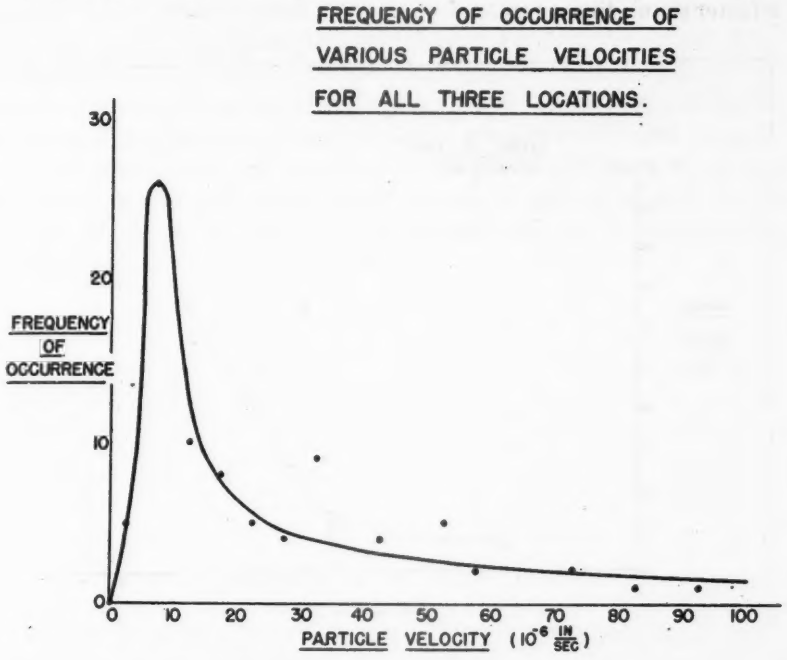

FIG. 3. Frequency of occurrence of various particle velocities. The dots represent the number of times (out of a total of eighty-one tests) particle velocities indicated on the abscissa were measured. All velocities falling between 0 and 5×10^{-6} inches per second are included at an abscissa value of $2\frac{1}{2}$. Similarly, all values between 5 and 10×10^{-6} inches per second are shown at $7\frac{1}{2}$, etc.

one-third of the cases observed useful reflection data would have been obtained through backgrounds of that level if sufficient sensitivity were available.

In Figure 4 are plotted the particle velocities measured against the effect of wind at one of the three locations. The black dots which indicate tests made are well scattered and the dotted curve can be considered to be indicative only. It is interesting that there was a very marked increase in background noise with changes of wind velocities after about 8 miles per hour. Velocities of 10 to 12 miles per hour gave much higher particle velocities with a jump from 10 millionths of an

inch per second at a wind velocity of 8 miles per hour to an average somewhere in the neighborhood of 75 millionths of an inch per second with wind velocities of 10 to 13 miles per hour. With the relative paucity of data available at this time no quantitative conclusions can be drawn to indicate the effect of wind on background noise for the areas in question. It would appear, however, that the noise was going up at a faster than a linear rate.

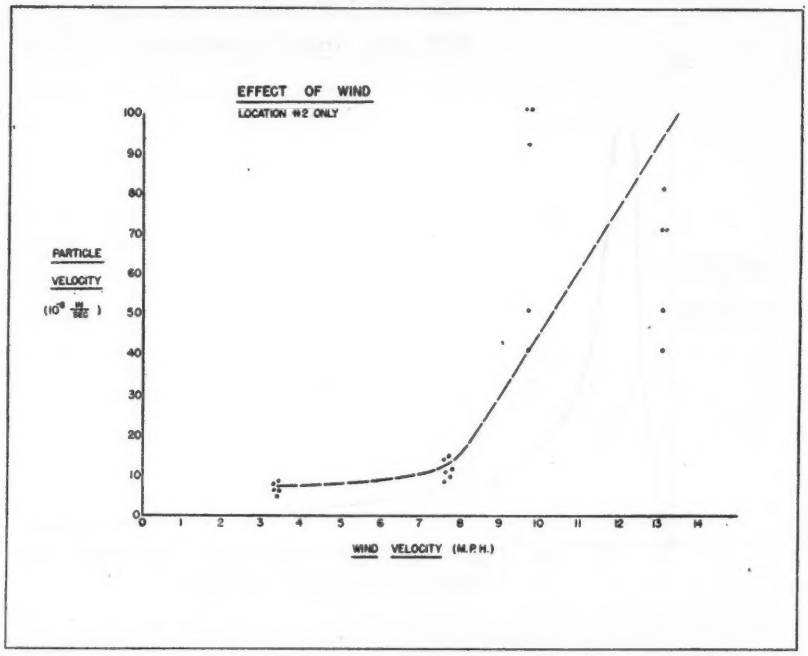

FIG. 4. Effect of wind on particle velocity. The dots in the two right-hand groups are so well scattered that the curve dashed in can be considered as indicative only of a trend. Each group of dots represents a series of tests made on the same day and immediately following one another. Since each test strip was only a few seconds in length, part of the wide spread in particle velocities in the two right-hand groups can undoubtedly be explained by the difficulty in correlating true wind velocities and their effect on ambient noise with the exact time during which the test strip was run.

CONCLUSION

In conclusion then, for at least three areas in Texas, minimum background noise with peak-to-peak particle velocities of the order of 3 to 10 millionths of an inch per second were very common, and that for these areas seismic systems should have sensitivities sufficient to amplify such velocities to a readable level for the recording device used. For example, assuming a sensitivity for the seismometer of 2

micro-volts per millionth of an inch per second, which is reasonably typical of good dynamic seismometers in use today, and a camera sensitivity of 5 inches per volt, which is again typical for string-type oscillographs, an amplifier gain of 20,000 from the output of the seismometer to the input of the oscillograph would be required to give a one-half inch deflection peak to peak on the oscillograph from a noise signal with a peak-to-peak particle velocity of $2\frac{1}{2}$ millionths of an inch per second. To repeat, this gain of 20,000 is from the output of the seismometer to the input of the oscillograph. Since amplifiers are frequently rated in terms of voltage gain from input to the amplifier to plate of the last stage, and a marked step-down is usual in going from the amplifier to the recording device plus other losses, the actual amplifier gain in such terms might be several million to achieve the 20,000 gain from the output of the seismometer to the input of the oscillograph.

DISCUSSIONS AND COMMUNICATIONS

DEEP ELECTRICAL PROSPECTING—A DISCUSSION*

SULHI YÜNGÜL†

ABSTRACT

In two papers published in GEOPHYSICS, one in the October, 1944, issue and the other in October, 1946, a system and method of calculation, called "Resistolog" method, was presented.[1,2] The object of the Resistolog method is to eliminate the effects of superficial inhomogeneities which are the most troublesome obstacles in interpreting electrical sounding results in exploring deep, horizontal discontinuities.

The following is a discussion of the papers mentioned above, mainly of the subject of (1) the apparent-resistivity formula derived for use with the Resistolog configuration, (2) determination of inflectional points on apparent resistivity curves, (3) depth of penetration, and (4) distortion caused by the "far electrode." A new method to determine inflectional points is also given. This paper includes a comprehensive knowledge about the forementioned papers and the reader may not have to refer to them.

The Resistolog method is an alteration of the well-known "single-electrode probe." The configuration used at Loma Alto-Seven Sisters area is shown in Figure 1. It is advantageous to refresh the reader's memory by quoting or summarizing significant parts from the authors' paper. These will be arranged as numbered paragraphs to which references will be made in the subsequent discussion.

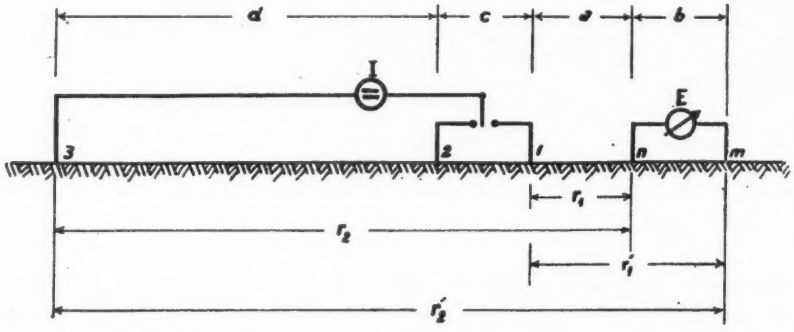

FIG. 1. Electrode arrangement.

(1) "An additional current electrode, 2, is placed in the vicinity of 1, preferably along the line determined by 1 and the potential electrodes. For each position of the potential electrodes two measurements of potential differences are made, one with current flow between 1 and 3 and the other with current flow between 2 and 3. These two

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[1] Thomas S. West and Clarence C. Beacham, *Precise Measurement of Deep Electrical Anomalies*, GEOPHYSICS, October, 1944.

[2] Thomas S. West and Clarence C. Beacham, *A Resistolog Survey of the Loma Alto-Seven Sisters Area of McMullen and Duval Counties, Texas*. GEOPHYSICS, October, 1946. This second article is a continuation of the first.

potential difference values along with corresponding current values and electrode separations provide data from which two apparent resistivity curves, R_1 and R_2 may be plotted."[3]

(2) "A ratio is then taken between the two resistivity values for each position of the potential electrodes. This provides data for a resistivity increment curve R_1/R_2, which is approximately independent of shallow inhomogeneities along the potential electrode traverse."[4]

(3) "Resistivity increment curve R_1/R_2 thus indicates the rate of variation of apparent resistivity with electrode separation and will therefore have maxima or minima corresponding to apparent resistivity curve inflection points. . . . For uniform conditions in the vicinity of 1 and 2 the resistivity increment curve R_1/R_2 will become unity at the point the apparent resistivity curve has a maximum or minimum, will be less than unity if apparent resistivity values are increasing with electrode separation, and greater than unity if these values are decreasing. Interpretation of resistivity increment curves is based entirely on resistivity increment curve maxima and minima, as described above."[5]

(4) "The distance between electrodes 2 and 3 is usually equal to or greater than the maximum depth to which prospecting is desired."[6]

(5) "The position of 3 is not critical. It is usually placed approximately collinear with 1 and 2 but various other positions, such as at right angles to the line of 1 and 2 or on the opposite side of the potential electrodes from 1 and 2 . . . have been employed."[7]

(6) "The average of the elevation of electrodes 1 and 2 is used in all cases for designating the elevation of the station. The location of the station is designated as the midpoint of the line joining electrodes 1 and 2, ..."[8]

(7) "For the electrode arrangement employed with the Resistolog procedure the formula for calculation of apparent resistivity is:

$$R_1 = 2\pi E/I[1/a - 1/(a+c+d) - 1/(a+b+c) + 1/(a+b+c+d)]. \cdots$$"[9]

To begin with, let us consider the formula given in (7). It seems that the third term in the brackets should be $1/(a+b)$ instead of $1/(a+b+c)$.

Supposing we have a point-source of strength I at the surface of the earth, which is considered homogeneous and semi-infinite. The potential gradient at a point P on the surface will be

$$dv/dr = -Ri, \tag{1}$$

where r is the distance of P from I, R the resistivity of the ground, i the current density and v the potential at P.

$$i = -I/2\pi r^2, \tag{2}$$

$$dv/dr = -RI/2\pi r^2, \tag{3}$$

$$v = RI/2\pi r. \tag{4}$$

[3] Thomas S. West and Clarence C. Beacham, *Precise Measurement of Deep Electrical Anomalies*, GEOPHYSICS, October, 1944, p. 498.

[4] *Ibid.*, p. 498–499.

[5] *Ibid.*, p. 500.

[6] *Ibid.*, p. 502.

[7] *Ibid.*, p. 502.

[8] *Ibid.*, p. 506.

[9] Thomas S. West and Clarence C. Beacham, *A Resistolog Survey of Loma Alto-Seven Sisters Area of McMullen and Duval Counties, Texas*, GEOPHYSICS, October, 1946, p. 495.

Let us consider the Resistolog notation in Figure 1 and suppose the electrode 1 is in operation. The potential at electrode n, due to current electrodes 1 and 3 will be

$$v_n = (R_1 I/2\pi)(1/r_1 - 1/r_2), \tag{5}$$

and at the electrode m due to the same current electrodes

$$v_m = (R_1 I/2\pi)(1/r_1' - 1/r_2'). \tag{6}$$

The potential between n and m is $v_n - v_m$,

$$v_n - v_m = E = (R_1 I/2\pi)(1/r_1 - 1/r_2 - 1/r_1' + 1/r_2'). \tag{7}$$

Using the Resistolog notations

$$R_1 = 2\pi E/I[1/a - 1/(a+c+d) - 1/(a+b) + 1/(a+b+c+d)]. \tag{8}$$

When the electrode 2 is in operation

$$R_2 = 2\pi E/I[1/(a+c) - 1/(a+c+d) - 1/(a+b+c) + 1/(a+b+c+d)]. \tag{9}$$

These formulas can be applied only when the electrodes are arranged as shown in Figure 1, and the position of the electrode 3 can not be "at right angles to the line of 1 and 2" as mentioned in (5). It could, of course, be on the opposite side of the potential electrodes if the proper signs are used. If the electrodes are arranged so that the effect of the far electrode is beyond the limits of the accuracy desired, that is, if the electrode 3 is far enough, then the electrode 3 may be anywhere on earth, but in that case a much simpler formula may be used instead of those of (8) and (9). This matter will be discussed later.

It seems that the most critical part of the Resistolog method is that maxima and minima of the "resistivity increment curve," R_1/R_2, do not correspond to inflectional points of the apparent resistivity curve (3). Let us consider the equations (8) and (9). When d is large compared to the other dimensions, and it should be so anyway as will be discussed later, the absolute values of the terms comprising d in the denominator are almost the same and near zero. As they are of opposite sign, let them cancel each other for the sake of the following reasoning. Then the equations (8) and (9) become

$$R_1 = 2\pi E/I[1/a - 1/(a+b)], \tag{10}$$

$$R_2 = 2\pi E/I[1/(a+c) - 1/(a+b+c)]. \tag{11}$$

Apparent-resistivity equations for a layered medium are very complicated, considering that E is also a function of electrode separation a. Without going into these complications let us see the following generalized relations:

When the electrode 1 is in operation the apparent resistivity is a function of a, and

$$R_1 = f(a), \text{ which is the same as } Y = f(x); \tag{12}$$

when electrode 2 is in operation,

$$R_2 = f(a+c), \text{ likewise } y = f(x+c). \tag{13}$$

This relation is seen in the equations (10) and (11). This means the curve R_2 is the same as R_1 shifted along the x-axis toward the point O by an amount equal to c (see Fig. 2). With the notations used, the irregularities caused by superficial inhomogeneities are not shifted and occur at the same electrode separation a. The apparent resistivity curve R_s at the station to which sounding is referred should of course be midway between the R_1- and R_2-curves. Then the main point is to determine the inflectional points on R_s. Let us consider that

$$u = R_1 - R_2 = Y - y = f(x) - f(x+c), \tag{14}$$

and see what it means. The curve u has maxima and minima which are given by

$$du/dx = f'(x) - f'(x+c) = 0. \tag{15}$$

Also

$$f'(x) = f'(x + c). \tag{16}$$

Suppose x_0 is one of the roots of equation (16). This already means that the slopes of the tangents to y and Y at x_0 are equal and also the tangents to y at x_0 and x_0+c are parallel. This means that on Y at least one inflectional point exists between x_0 and x_0+c, because to each value of x there corresponds only one value of Y. Likewise the tangents to y at x_0 and x_0-c are parallel, and an inflectional point exists between x_0 and x_0-c. The segment of Y between x_0 and x_0+c is identical with the segment of y between x_0 and x_0-c, the latter being shifted in a direction parallel to x-axis. In practice it may be assumed without making an appreciable error, that the two inflectional points on y and Y are symmetrical with respect to the line $x=x_0$. Then if another current electrode was employed at the station, midway between the electrodes 1 and 2, an apparent-resistivity curve, R_s, would be obtained. On R_s the inflectional point would be at x_0, midway between the two inflectional points. This may be shown very simply in case of two cubic equations,

$$y = a_0x^3 + a_1x^2 + a_2x + a_3,$$
$$Y = a_0(x + c)^3 + a_1(x + c)^2 + a_2(x + c) + a_3.$$

The root of $Y'-y'=0$ is $x_0=-c/2-a_1/3a_0$, the inflectional point of the Y-curve is at $x_1=-c-a_1/3a_0$, and that of y-curve is at $x_2=-a_1/3a_0$, x_0 being midway between x_1 and x_2.

The result is that maxima and minima of the (R_1-R_2)-curve correspond to inflectional points of the apparent-resistivity curve at the station to which sounding is referred. In case of actual field measurements, supposing the two curves are affected equally by a superficial inhomogeneity, the (R_1-R_2)-curve will give the inflectional point precisely.

When the Resistolog procedure is followed the R_1/R_2-curve does not give the inflectional points of the apparent-resistivity curve, and the interpretation using the maxima and minima on the Resistolog curve leads to erroneous results. It however gives the minima and maxima of the apparent-resistivity curve, just as R_1-R_2 does. These points have no value in quantitative depth determinations, but may be used for correlating. Figure 2 shows a descriptive example. The R_1/R_2- and (R_1-R_2)-curves were plotted from the measurements of the R_1-R_2-curve (note how much the Resistolog result is shifted from the actual inflectional point on R_s).

Another line of discussion is the "exploration-depth" rather "depth-of-penetration" problem. In the Resistolog procedure, the a of an inflectional point is taken as the depth to the layer corresponding to this point, unless a depth-vs.-electrode-separation curve is plotted experimentally over a known area and applied over the unknown parts of the same area, as shown by the curve on page 525, GEOPHYSICS, October, 1944.

Let us consider the electrode 1 is in operation. The depth of penetration is approximately

$$h_1 = (r_1 - r_1')/2, \tag{17}$$

if $b \ll (r_1-r_1')/2$, which is the usual case in practice. When electrode 2 is in action, likewise

$$h_2 = (r_2 - r_2')/2. \tag{18}$$

For the station it will be the average, and with the notations used

$$h_s = a + b/2 + c/2. \tag{19}$$

Then the curves should be plotted against the distance between the midpoints of potential electrodes and 1 and 2.

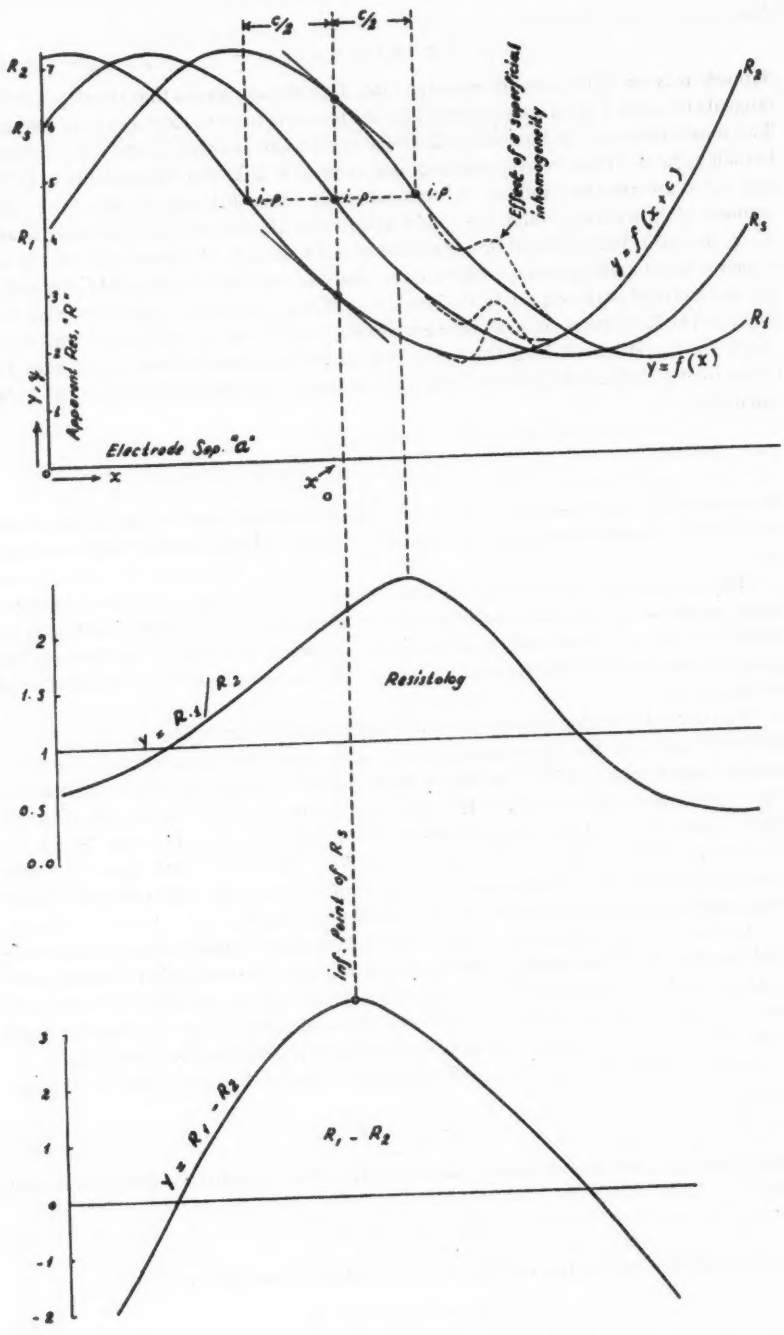

FIG. 2. Apparent Resistivity, Resistolog and (R_1-R_2)-curves.

Finally, let us take the distance d into consideration. The arrangement used at Loma Alto-Seven Sisters is such that $d = 2{,}400$–$3{,}400$ feet, $c = 600$ feet, $b = 600$ feet, and the depth attained is 3,400 feet, at station 46 for instance. We proceed supposing the inflectional points of an apparent-resistivity curve thus obtained correspond to depths to resistivity discontinuities, as in the case of a theoretical single current electrode. Although we take the far electrode into account to calculate R_1 and R_2 by the formulas (8) and (9), if d is only 2,400 feet when a is 3,400 feet, the distortion due to the far electrode is so great that the procedure is no longer a single-electrode probe. The depth control becomes very complicated and inflectional points no longer correspond to discontinuities. In order to proceed as it is intended here one must use a much greater distance d, let us say at least four times what has been used at Seven Sisters to explore a depth of 4,000 feet (according to equation (19)). Thus we are forced to take d much larger. It would be best then to use the simplified formulas (10) and (11) throughout the work. The precision would be more than satisfactory.

DEEP ELECTRICAL PROSPECTING—A REPLY*

THOMAS S. WEST†

Mr. Yüngül's review of the "Resistolog" procedure has been read with interest. The primary reason for publishing Resistolog data was the hope that a mathematical explanation for the observed phenomena would result. Mr. Yüngül's paper is most welcome inasmuch as it represents an effort in the desired direction.

However, the really important question still remains unanswered. We know of no mathematical analysis which explains the relatively sharp Resistolog features with large electrode separation. As shown in our papers, relatively sharp Resistolog maxima and minima were consistently observed with electrode spacings (distance R_1 Fig. 1) ranging from 2,000–6,000 feet. These features resulted in definitely correlatable Resistologs which could be duplicated quite closely by independent check at a nearby station. Furthermore, difference in depth indicated by these correlations agreed quite closely with true structural differences in cases in which structural difference between stations were known or subsequently determined.

As further evidence of the depth from which Resistolog features originated, several apparently positive cases of direct detection of oil and gas saturation are shown in which a given Resistolog maxima is present in all Resistologs in the oil-saturated area and absent from all Resistologs in the surrounding area. We therefore regard the experimental evidence of such features as conclusive. It is our hope that equally conclusive mathematical analysis will ultimately be developed.

With more specific reference to Mr. Yüngül's paper, formulas (8) and (9) for calculation of resistivity are correct. The formula published in our paper apparently represents a stenographic error which was not corrected. The formula actually employed was that shown by Mr. Yüngül. The practical application of these rather long formulas was not cumbersome because tables were calculated for the electrode configuration and series of electrode separations employed. Since the same magnitude of current flow was always employed for electrode 1 as for electrode 2, the formula employed reduced to $(E_1/E_2)K = R_1/R_2$ in which E_1 and E_2 were the observed potential-difference values for current flow to electrodes 1 and 2 for a given potential electrode position, and K a value read from the table. Mr. Yüngül's proposal for shortening the calculation is cer-

* Manuscript received by the Editor October 6, 1947.

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tainly permissible, however. A still further simplification of calculation is also permissible in relatively deep prospecting. With relatively large electrode separation the potential difference ratio E_1/E_2 may be employed instead of the corresponding resistivity ratio R_1/R_2. The ratio E_2/E_1 was used instead of R_2/R_1 in the Resistologs shown in Figures 10 and 11 of our first paper.

It is not necessary for Resistolog maxima or minima to occur at the same electrode separation as does the resistivity-curve inflection points for interpretation by correlation and comparison with other Resistologs in the same area. For interpretation by analytical methods, this discrepancy might conceivably be undesirable in some cases. However, the mere fact that Resistolog maxima and minima do not have the identical relation between electrode separation and depth to the layer causing such feature as exists in case of apparent resistivity-curve inflection points does not preclude interpretation, by analytical methods.

The implication that the resistivity difference R_1-R_2 is preferable to the ratio R_1/R_2 has one serious objection. The general form of the apparent resistivity curve is $R=S(1+F)$ in which R is apparent resistivity, S the resistivity of the surface layer and F a quantity which varies with the electrode configuration and with the depth, resistivity, thickness, etc. of the various subsurface layers. When applied to two different electrodes such as 1 and 2, this formula becomes $R_1=S(1+F_1)$ and $R_2=S(1+F_2)$. Therefore, $R_1-R_2=F_1-F_2$ and $R_1/R_2=(1+F_1)/(1+F_2)$. It is thus evident that R_1-R_2 is not independent of the value of S. Since the resistivity of the surface layer may vary from one potential-electrode position to another, features may be introduced into the (R_1-R_2)-curve because of shallow inhomogeneities.

Small features on the (R_1-R_2)-curve corresponding to large inhomogeneities along the potential-electrode traverse have been observed in actual field data. Although such features were small in proportion to shallow inhomogeneities, they were in some cases as large as features attributed to subsurface beds. Any gain in interpretation by use of the (R_1-R_2)-curve would be more than offset because of the lack of complete independence of shallow inhomogeneities. In relatively deep prospecting very small residual errors from shallow inhomogeneities would in many cases be sufficient to prevent positive correlation of Resistologs. The same is true of errors of observation. We have many cases in which the taking of additional data resulted in positive correlation of Resistologs which did not initially appear to correlate.

In contrast to the (R_1-R_2)-curve, it is to be noted that the (R_1/R_2)-or (R_2/R_1)-curve is entirely independent of the resistivity of the surface layer.

Field results do not indicate the distance d to be as critical as suggested by Mr. Yüngül. For example Figure 7 of our first paper shows a case in which distance from electrode 3 to the midpoint of the potential electrodes was decreased by 1,800 feet (from 6,850 to 5,050 feet) by moving electrode 3 to a position at a right angle to the remainder of the electrode system. No change in magnitude of the Resistolog features nor severe distortion resulted. Also in a number of cases electrode 3 was left stationary for a series of stations along a straight line traverse. In some cases d was varied by as much as 3,000 feet (from 3,000 to 6,000 feet) without an observable change in the Resistolog feature. It is possible that the value of d might be more critical for relatively shallow prospecting in which considerable resistivity contrast exists. Most of our field experiments with this procedure were conducted with relatively large electrode spreads, i.e. $r_1=2{,}000$ to 6,000 feet, b and c 600 feet, and d 3,400 feet.

PATENTS*

The Patents below are listed in accordance with the complete classification as published in GEOPHYSICS, April, 1947.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,424,357, C. B. Horsley. Iss. 7/22/47. App. 12/10/45. Assign. Ultrasonic Corp.

Method of and Apparatus for Modulating the Frequency of Sound Waves. A high-power supersonic wave modulator in which the vibrations are transmitted through a column of fluid and the fluid moved alternately in opposite directions in the column.

U. S. No. 2,424,375. W. A. Van Allen. Iss. 7/22/47. App. 2/21/46. Assign. Ultrasonic Corp.

Modulator for Sound Waves. A high-power supersonic compressional wave modulator having a reciprocating reflecting piston at a bend in the conduit carrying the sound.

U. S. No. 2,424,634. F. Rieber. Iss. 7/29/47. App. 5/19/44. Assign. Interval Instruments, Inc.

Theater-Amplifying and Sound-Distributing System. A public-address system in which a number of microphones are placed at various distances from the source and their signals respectively delayed by an amount to bring the signals into synchronism, amplified and distributed to loud speakers placed about the auditorium, the speaker signals being respectively delayed by an amount so that the speaker sound is emitted in synchronism with the arrival of sound from the source at the speaker location.

U. S. No. 2,425,003. P. K. Potter. Iss. 8/5/47. App. 12/23/44. Assign. Bell Telephone Laboratories, Inc.

Analysis and Representation of Complex Waves. A system for the spectral representation of speech waves, the sound being first recorded on an endless magnetic tape and then repeatedly analyzed for the time-sequences of various frequencies which are recorded on a chart in the form of amplitude contours.

U. S. No. 2,427,569. A. McL. Nicolson. Iss. 9/16/47. App. 4/20/43.

Wave-Sensitive and Wave-Front Detecting Apparatus. A sound-ranging system having several groups of detectors and indicating which detector of each group first receives the wave.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,424,511. R. M. Stanley and J. F. Strickler, Jr. Iss. 7/22/47. App. 3/29/44. Assign. Bell Aircraft Corp.

Aircraft Flight Instrument. An air-speed indicator having a pair of pointers one of which shows actual air speed and the other shows maximum safe air speed for the aircraft at the temperature and compressibility of the surrounding air.

U. S. No. 2,424,763. H. J. Marschak. Iss. 7/29/47. App. 2/15/45.

Speed-Computing and Map-Reading Device. A map-reading device having a strip map and a position-locating index which is driven or set in proportion to elapsed time.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

U. S. No. 2,424,796. W. L. Carlson. Iss. 7/29/47. App. 10/28/43. Assign. Radio Corp. of America.

Superheterodyne Radio Altimeter or Locator. A system for obtaining high amplification in a cyclically frequency-modulated radio altimeter by heterodyning both the reflected signal and a portion of the transmitted signal against a local oscillator.

U. S. No. 2,424,854. R. C. Sanders, Jr. Iss. 7/29/47. App. 8/29/42. Assign. Radio Corp. of America.

Pulsed Frequency-Modulated Altimeter. A cyclically frequency-modulated radio altimeter in which both the reflected signal and a portion of the transmitted signal are applied to a beat detector and the transmitted pulse lasts through one cycle of frequency modulation and the receiver is blocked during the off period.

U. S. No. 2,425,541. H. Konet. Iss. 8/12/47. App. 7/3/44. Assign. Bendix Aviation Corp.

Photoelectric Drift Indicator. An airplane drift indicator in which the ground image is focused through a rotating grid and onto a synchronously rotating elongated photocell, the difference in phase between rotation of the grid and rotation of the photocell being indicated.

U. S. No. 2,426,184. E. M. Deloraine and G. J. Lehmann. Iss. 8/26/47. App. 3/13/44. Assign. Federal Telephone and Radio Corp.

Radio-Guiding System. An arrangement for permitting the pilot of an aircraft to observe the ground through a half-silvered mirror which simultaneously permits him to observe a superimposed radar screen image.

U. S. No. 2,426,207. A. G. Handy. Iss. 8/26/47. App. 2/2/45.

Aerial Viewer with Obstacle-Bypassing Optical System Comprising Lens and Mirror Means. A system of mirrors and eye piece arranged so that a pilot can observe the ground under him in a viewer on the instrument panel with the optical path arranged to clear a centrally located landing gear.

U. S. No. 2,426,228. L. Mackta. Iss. 8/26/47. App. 10/31/42.

Speed Indicator. An airplane ground-speed indicator in which two divergent uhf radio beams are projected to the ground and reflected components received on the plane and the Doppler effect between them observed.

32—BLASTING MACHINE

U. S. No. 2,428,334. B. L. Lubelsky and R. E. Hartline. Iss. 9/30/47. App. 7/7/41 and 7/12/44. Assign. Mine Safety Appliances Co.

Protective Device for Blasting Circuits. A circuit breaker which opens the circuit after a short time delay and which has both a series coil and a shunt coil wound on the core in aiding relation.

48—CASING PERFORATOR

U. S. No. 2,426,517. C. J. McWorter. Iss. 8/26/47. App. 12/26/44.

Gun Perforator. A repeating shot gun perforator which has an electric motor to move the gun barrel from a longitudinal position to a lateral position and after firing returns it to a longitudinal position and reloads.

64—COMMUNICATION DEVICE

U. S. No. 2,423,459. W. P. Mason. Iss 7/8/47. App. 9/15/42. Assign. Bell Telephone Laboratories, Inc.

Frequency-Selective Apparatus. A filter system for a multiplex modulated carrier-wave communication system in which the multiplex signal is converted to a supersonic beam in a liquid and frequency separation effected by a prism and lens focusing onto receivers in the liquid.

68—COMPUTING DEVICES

U. S. No. 2,423,394. L. Lee, II. Iss. 7/1/47. App. 12/30/43. Assign. Niles-Bement-Pond Co.

Device for Measuring the Ratio Between Two Variables. Apparatus for indicating the ratio of two pressures by applying each to a mercury manometer chamber the other side of which has a variable area and has a column of lighter liquid which rises to a height representing the logarithm, and using a differential pressure indicator between the two lighter liquids.

108—ECHO SOUNDING

U. S. No. 2,424,030. H. C. Hayes. Iss. 7/15/47. App. 1/30/32.

Balanced Driver for Sonic Depth Finders. An echo-sounding circuit using a single transducer for sending and receiving by having the driving transformer secondary feed the transducer and an equivalent electric circuit in series and connecting the receiving amplifier from the common junction to the mid-point of the transformer secondary.

U. S. No. 2,424,549. R. Black, Jr. and F. F. Romanow. Iss. 7/29/47. App. 7/14/43. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal Detector or Receiver. A spherical hydrophone having diametrically located inertia-type transducers connected in series, and an acoustic phase-shifting air capsule in the hydrophone case wall opposite one of the transducers.

U. S. No. 2,424,773. F. Rieber. Iss. 7/29/47. App. 2/26/44. Assign. Interval Instruments, Inc.

Locating Device. A sound-ranging apparatus in which the microphone signals are magnetically recorded on endless tapes or disks so that they may be played back repeatedly for analysis to determine the direction to the sound source.

U. S. No. 2,424,981. B. M. Harrison. Iss. 8/5/47. App. 2/27/43. Assign. Submarine Signal Co.

Signaling System. An indicator for an echo-sounding system having a neon lamp which lights when the reflection is received, the light shining through the intersection of spiral slits on two concentric revolving drums and read on an adjacent fixed scale.

U. S. No. 2,425,594. W. J. Brown. Iss. 8/12/47. App. 3/4/43. Assign. Western Electric Co., Inc.

Submarine Signal Microphone. A ship's hydrophone arranged with two electromechanical units both of which are affected by ship's noises and only one of which responds to outside noises and connected so that the ship's noises cancel out.

112—ELECTRIC CONNECTOR

U. S. No. 2,427,377. A. J. Zschokke. Iss. 9/16/47. App. 5/30/42. Assign. Lane-Wells Co.

Contact Means for Electrically-Operated Well Tools. An arrangement for effecting electrical connection between a gun perforator and a go-devil which carries the firing batteries, the contacts being protected by a rupturable insulating material.

116—ELECTRIC LOGGING

U. S. No. 2,425,868. L. Dillon. Iss. 8/19/47. App. 8/28/36. Assign. Union Oil Co.

Method and Apparatus for Logging Drill Holes. A method of logging or surveying in which the parameter logged is converted into mechanical vibrations whose frequency is related to the parameter and the vibrations picked up at the surface and indicated on a frequency meter.

U. S. No. 2,425,869. L. Dillon. Iss. 8/19/47. App. 8/28/36 and 6/5/43. Assign. Union Oil Co.

Method and Apparatus for Logging Drill Holes. A method of resistivity logging in which the change in balance of a Wheatstone bridge changes the frequency of a mechanical oscillator in the logging apparatus and the vibrations are picked up at the surface and indicated on a frequency meter.

U. S. No. 2,426,335. T. A. Banning, Jr. Iss. 8/26/47. App. 11/8/43.

Side-Wall Sampling Apparatus. A device having a side-wall sample cutter hydraulically operated from explosive gas pressure, the device also having electric connections for positioning with respect to a known electric log.

U. S. No. 2,427,950. H. G. Doll. Iss. 9/23/47. App. 1/1/43. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Determining the Dip of Strata Traversed by a Borehole. An electric dipmeter which has three small laterally spaced electrodes on arms which are urged against the borehole wall and which makes separate electric logs whose vertical displacement may be compared.

U. S. No. 2,428,034. C. R. Nichols and S. H. Williston. Iss. 9/30/47. App. 4/13/36. Assign. Sperry-Sun Well Surveying Co.

Electrical Prospecting Apparatus. A self-contained electric logging apparatus which periodically photographs galvanometers in the circuit, the electrodes being on the case of the apparatus or formed by the drill stem and an insulated drill bit.

128—ELECTROMAGNETIC LOGGING

U. S. No. 2,428,155. H. Guyod. Iss. 9/30/47. App. 4/19/43.

Method and Apparatus for Logging Boreholes. An electromagnetic dipmeter in which a rotating radial magnetic field is set up in the hole and the eddy-current potential measured with an electrode leading to a recorder at the surface.

132—ELECTROMAGNETIC PROSPECTING

U. S. No. 2,426,918. W. M. Barret. Iss. 9/2/47. App. 3/17/41. Assign. Engineering Research Corp.

Method for Electromagnetic-Wave Investigations of Earth Formations. A method of determining depth to an electromagnetic-wave reflector by setting up a sending station and a receiver some distance away, measuring a parameter of the combined direct and reflected waves and observing successive maxima and minima as the frequency is varied.

136—EXPLOSIVE

U. S. No. 2,423,255. F. H. Rolfes. Iss. 7/1/47. App. 6/29/43.

Clip for Holding Detonators in Blasting Cartridges. A copper-wire clip having a loop which embraces the detonator fuse or cable and prongs which engage the cartridge.

U. S. No. 2,424,374. J. Taylor and H. R. Wright. Iss. 7/22/47. App. 7/29/42 and 5/20/43. Assign. Imperial Chemical Industries Ltd.

Explosive Booster. An explosive booster having a detonating component and a flame-insensitive compressed charge followed by a flame-insensitive cast charge of lower sensitivity.

U. S. No. 2,425,176. L. B. Counterman. Iss. 8/5/47. App. 8/4/43. Assign. Hercules Powder Co.

Explosive Cartridge Unit. A dynamite cartridge and sleeve for assembling cartridges end-to-end, the cartridge and sleeve having external and internal threads with serrated edges which lock and prevent slipping when there is any tendency to pull the assembly apart.

U. S. No. 2,425,472. J. E. Hodgson and E. V. Abel. Iss. 8/12/47. App. 8/12/43. Assign. Continental Can Co., Inc.

Container for Explosives. A tin can for explosive, the can having along one side an internal channel accessible through holes in the side into which the detonator may be inserted.

U. S. No. 2,425,741. H. B. Humphrey. Iss. 8/19/47. App. 4/23/45.

Safety Primer for Blasting. An arrangement for holding a blasting cap centered in the charge by a frangible sleeve which may split and spread under tamping pressure.

U. S. No. 2,427,899. L. A. Burrows. Iss. 9/23/47. App. 9/4/40. Assign. E. I. du Pont de Nemours & Co.

Blasting Cap. A fuse-fired blasting cap having a dead-pressed charge of mannitol hexanitrate between the ignition and primer charges.

U. S. No. 2,428,334. B. L. Lubelsky and R. E. Hartline. Iss. 9/30/47. App. 7/7/41 and 7/12/44. Assign. Mine Safety Appliances Co.

Protective Device for Blasting Circuits. A circuit breaker which opens the circuit after a short time delay and which has both a series coil and a shunt coil wound on the core in aiding relation.

140—FLAW DETECTOR

U. S. No. 2,423,552. J. E. Clarke. Iss. 7/8/47. App. 9/10/41 and 5/28/42. Assign. Magnaflux Corp.

Magnetic Testing Apparatus. A magnetic flaw-detecting apparatus in which a high current is initially sent through the specimen and the current reduced a short time later so that inspection may be carried out at reduced current but due to hysteresis with little flux reduction.

U. S. No. 2,423,891. F. Kellerman. Iss. 7/15/47. App. 6/17/44. Assign. Magnetic Analysis Corp.

Bifrequency Magnetic Testing Apparatus. Apparatus for electromagnetic inspecting

of magnetic material to locate flaws, the material being passed through two sets of primary coils excited by a.c., each having secondary coils whose outputs are rectified, filtered and their balance indicated.

U. S. No. 2,425,857. W. C. Barnes and H. W. Keevil. Iss. 8/19/47. App. 9/24/43.

Apparatus for Detecting Flaws in Rails. A magnetic flaw detector for rails which demagnetizes the rail after test so that ferromagnetic material does not accumulate at insulated rail joints and interfere with block signal operation.

148—FLOW METER

U. S. No. 2,425,691. N. Brewer. Iss. 8/12/47. App. 9/25/45. Assign. Fischer & Porter Co.

Magnetic Couple for Flowmeters or the Like. A magnet system for coupling a rotameter float to an indicator arm, the float carrying two bar magnets placed end-to-end with like poles together and the arm having a follower magnet one pole of which is attracted by the common pole of the float bar magnets.

U. S. No. 2,425,720. C. P. Bergman. Iss. 8/19/47. App. 11/4/43. Assign. Rockwell Manufacturing Co.

Compound Meter. A flow meter having a large flow meter and a small flow meter in series with a controlled by-pass valve around the small meter, operation of the valve also operating a clutch to the register.

160—GALVANOMETER

U. S. No. 2,424,823. C. M. Hathaway. Iss. 7/29/47. App. 9/25/44. Assign. Hathaway Instrument Co.

Galvanometer Movement Mounting. A galvanometer unit for a watt galvanometer having a bifilar element mounted on the front cover and coil with pole pieces in the body of the unit.

U. S. No. 2,425,407. H. W. Washburn. Iss. 8/12/47. App. 12/9/43. Assign. Consolidated Engineering Corp.

Galvanometer. A coil assembly for a multi-element oscillograph in which each coil assembly has a pair of soft iron pole pieces which may be rotated by an external projection and also a zero coil adjustment.

U. S. No. 2,425,408. A. J. Williams, Jr. and O. B. Tatman. Iss. 8/12/47. App. 11/2/44. Assign. Leeds and Northrup Co.

Frictional Damping Means for Galvanometers. A longitudinal vibration damping support for the moving system of a galvanometer in which the upper and lower suspensions are mounted on light cantilever springs and carried over rounded upper and lower bridges against which the suspensions rub when longitudinal vibrations occur.

168—GAS ANALYSIS

U. S. No. 2,427,261. F. W. Crawford. Iss. 9/9/47. App. 9/30/39. Assign. Phillips Petroleum Co.

Method for Analyzing Gas. A method of soil-gas analysis in which CO_2 and H_2O are removed chemically, hydrocarbons heavier than methane condensed by liquid nitrogen, methane determined by combustion and the higher hydrocarbons determined by a sensitive pressure gauge on heating.

172—GEOCHEMICAL PROSPECTING

U. S. No. 2,423,774. J. J. Heigl. Iss. 7/8/47. App. 4/2/42. Assign. Standard Oil Development Co.

Oil Determination. A method of determining oil in samples by extracting with a petroleum solvent, measuring the light absorption of the extract and comparing with the absorption of the pure solvent.

192—INCLINOMETER

U. S. No. 2,424,358. G. L. Kothny. Iss. 7/22/47. App. 7/22/43. Assign. Sperry-Sun Well Surveying Co.

Well Surveying Device. A pendulum inclinometer using electrolytic marking of a record disc and having in the circuit a conducting fluid which drains through an orifice and shuts off the recording current after a time so that false records are eliminated.

200—LEVEL INDICATOR

U. S. No. 2,427,690. C. W. Peterson. Iss. 9/23/47. App. 11/26/45.

Liquid Measuring System. A tank-level gauge glass with a compressed air supply connected through a rotatable plug-valve to the U-tube ports so that the latter may be blown clear of foreign materials.

216—MAGNETIC COMPASS

U. S. No. 2,424,562. C. F. Fragola. Iss. 7/29/47. App. 3/31/42 and 3/31/44. Assign. Sperry Gyroscope Co., Inc.

Gyro Flux-Valve Compass System. A compass system in which drift of the gyro is corrected by an electromagnetic precessing control operating in response to the difference in signals between a horizontal flux-valve compass and a shielded flux valve which detects the gyro orientation.

U. S. No. 2,426,470. A. T. Sinks. Iss. 8/26/47. App. 7/30/45. Assign. General Electric Co.

Remote-Indicating Magnetic-Compass System. A system for remotely indicating the position of a pivoted compass magnet by surrounding it with an annular core excited with polyphase a.c. connected to a similar annular core on the indicator, and with a third single-phase-excited annular core in the circuit having adjustable magnets to provide deviation compensation.

U. S. No. 2,427,654. L. F. Beach. Iss. 9/23/47. App. 7/30/40 and 3/15/43. Assign. Purves Corp.

Remote-Reading Flux-Valve Compass System. A remote direction-indicating magnetic-compass system having three flux valves oriented at 120° and connected to a direction indicator of the Selsyn type.

U. S. No. 2,428,346. W. G. White. Iss. 9/30/47. App. 3/11/47.

Magnetic Compass. A mariner's compass which has a compass card suspended in a spherical container full of transparent liquid and also has a saucer-shaped member suspended in the container close to the compass card to help damp the latter without causing deviations.

224—MAGNETIC RECORDER

U. S. No. 2,423,339. W. E. Newman. Iss. 7/1/47. App. 7/29/44. Assign. Radio Corp. of America.

Reproducing Head for Magnetic Telegraphones. A magnetic-recorder reproducing head in which a magnetic shunt is rotated or oscillated adjacent the pole pieces to produce modulation.

U. S. No. 2,424,218. S. J. Begun. Iss. 7/22/47. App. 1/30/43. Assign. The Brush Development Co.

Magnetic Recording-Reproducing Means and System. A system for magnetically recording and reproducing low-frequency transients in which the signal is recorded on an endless magnetic tape and reproduced by running the tape at a higher speed past a reproducing head connected to a c.-r. tube with synchronized sweep.

U. S. No. 2,424,295. A. L. W. Williams. Iss. 7/22/47. App. 7/21/43. Assign. The Brush Development Co.

Rotatable Magnetic-Reproducing Means. A magnetic-tape reproducing head which will reproduce low frequencies, the head being cylindrical with a transverse coil and rotated close to the tape by a motor.

U. S. No. 2,424,498. H. Nygaard. Iss. 7/22/47. App. 3/2/45. Assign. Lear, Inc.

Continuous Magnetic-Recording System. A magazine for a magnetic wire recorder having a pair of reels and mechanism for spooling the wire uniformly onto and from the reels.

U. S. No. 2,424,633. F. Rieber. Iss. 7/29/47. App. 5/19/44. Assign. Interval Instruments, Inc.

Acoustic Reservoir for Use in a Magnetic Sound Recording and Reproducing System. A magnetic recording-reproducing system having a drum with a spirally wound recording wire and a recording head which is broad enough to cover a number of turns of the recording wire.

U. S. No. 2,424,697. W. P. Lear. Iss. 7/29/47. App. 5/12/45. Assign. Lear, Inc.

Magnetic Recorder. A magazine which latches onto a magnetic-recorder unit and which has a rewind reel and a storage reel and an indicator to show the remaining recording time.

U. S. No. 2,425,213. D. E. Sunstein. Iss. 8/5/47. App. 5/5/45. Assign. Philco Corp.

Magnetic-Wire Telegraphone System. A magnetic wire-recording system which records a carrier signal at right angles to the speech signal, the carrier signal being used for volume compression and expansion.

U. S. No. 2,426,838. H. B. Miller. Iss. 9/2/47. App. 4/18/45. Assign. The Brush Development Co.

Endless Tape Magnetic Recording-Reproducing Device. A magnetic-tape recorder in which the tape is lubricated and spirally wound on itself, the tape being taken from the inside convolution through a cross-over loop and through the recording head and then wound on the outside again.

U. S. No. 2,427,193. B. L. Canfield. Iss. 9/9/47. App. 12/26/44. Assign. C. G. Conn, Ltd.

Reel for Magnetic Recording Apparatus. A double reel for a magnetic wire having an inner reel which winds up the leader and an outer reel which is automatically engaged by the coupling between leader and wire and which winds up the wire.

U. S. No. 2,428,002. E. L. Barrett. Iss. 9/30/47. App. 3/9/45. Assign. Barrett-Keenan Co.

Wire-Type Recording and Reproducing Apparatus. A magnetic-wire recorder in which the wire is stored inside a stationary U-shaped annular container from which it is drawn by a friction roller, fed through the erasing and reproducing heads and longitudinally shoved into another similar container.

228—MAGNETIC TESTING

U. S. No. 2,423,552. J. E. Clarke. Iss. 7/8/47. App. 9/10/41 and 5/28/42. Assign. Magnaflux Corp.

Magnetic Testing Apparatus. A magnetic flaw-detecting apparatus in which a high current is initially sent through the specimen and the current reduced a short time later so that inspection may be carried out at reduced current but due to hysteresis with little flux reduction.

U. S. No. 2,423,891. F. Kellerman. Iss. 7/15/47. App. 6/17/44. Assign. Magnetic Analysis Corp.

Bifrequency Magnetic Testing Apparatus. Apparatus for electromagnetic inspection of magnetic material to locate flaws, the material being passed through two sets of primary coils excited by a.c., each having secondary coils whose outputs are rectified, filtered and their balance indicated.

U. S. No. 2,427,774. G. Fredrickson. Iss. 9/23/47. App. 10/9/43. Assign. General Motors Corp.

Method and Apparatus for Magnetically Testing the Hardness of Paramagnetic Objects. A method of determining hardness of heat-treated steel pieces by magnetizing to saturation, then applying a partially demagnetizing field and then testing the residual magnetism by centrifugally measuring the clinging ability of the piece to a rotating steel plate.

232—MAGNETOMETER

U. S. No. 2,424,772. F. Rieber. Iss. 7/29/47. App. 7/13/43. Assign. Interval Instruments, Inc.

System for Detecting Magnetic Masses. An airborne magnetic variometer having two spaced pick-up coils on a common shaft rotated by a propeller and connected to a bridge circuit to indicate unbalance of induced voltages.

U. S. No. 2,425,180. C. H. Fay. Iss. 8/5/47. App. 12/15/43. Assign. Shell Development Co.

Magnetic Field Measurements. A magnetometer having an elastically suspended coil carrying a mirror which reflects a beam of light onto a photocell, the photocell output being amplified and fed back to the coil to sustain oscillation, indication being obtained by the amplification required or by the amplitude of oscillation.

U. S. No. 2,426,622. A. G. Laird and T. Slonczewski. Iss. 9/2/47. App. 9/21/44. Assign. Bell Telephone Laboratories, Inc.

Magnetic Field Detector. A saturated-core reactor-type of magnetometer which is

excited at a sinusoidal fundamental frequency and whose output circuit responds to preselected even-order harmonics, the filters being arranged to allow circulation through the magnetometer element of all other harmonics.

U. S. No. 2,427,014. W. J. Means. Iss. 9/9/47. App. 7/30/43. Assign. Bell Telephone Laboratories, Inc.

Orienting Device. Apparatus for orienting a gimbal-mounted device in which the coupling to the device for rotation about the inner gimbal axis passes through the axis of the outer gimbal ring.

U. S. No. 2,427,666. E. P. Felch, Jr. and T. Slonczewski. Iss. 9/23/47. App. 4/20/43. Assign. Bell Telephone Laboratories, Inc.

Magnetic Field-Strength Indicator. A magnetometer having three mutually perpendicular flux valves whose second harmonic outputs are separately squared and the fourth harmonics added together and indicated.

U. S. No. 2,428,014. R. S. Curry and C. F. Fragola. Iss. 9/30/47. App. 2/3/43. Assign. Sperry Gyroscope Co., Inc.

Concentric-Core Flux Valve. A flux-valve construction having a central core with flanges between which the exciting coil is wound surrounded by a tubular core outside of which the pick-up coil is wound.

236—MASS SPECTROMETRY

U. S. No. 2,427,484. S. S. West. Iss. 9/16/47. App. 10/22/43. Assign. Stanolind Oil and Gas Co.

Ionic Gas Analysis. An ion-source for a mass spectrometer in which successive slits are displaced so that only ions formed with initial kinetic energy may pass and be measured.

244—MICROPHONE

U. S. No. 2,424,549. R. Black, Jr. and F. F. Romanow. Iss. 7/29/47. App. 7/14/43. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal Detector or Receiver. A spherical hydrophone having diametrically located inertia-type transducers connected in series, and acoustic phase-shifting air capsule in the hydrophone case wall opposite one of the transducers.

U. S. No. 2,425,594. W. J. Brown. Iss. 8/12/47. App. 3/4/43. Assign. Western Electric Co., Inc.

Submarine Signal Microphone. A ship's hydrophone arranged with two electromechanical units both of which are affected by ship's noises and only one of which responds to outside noises and connected so that the ship's noises cancel out.

U. S. No. 2,427,062. F. Massa. Iss. 9/9/47. App. 6/2/44. Assign. The Brush Development Co.

Vibrational-Energy Transmitter or Receiver. A piezoelectric transducer having a piston whose parts are driven at different amplitudes in order to improve directivity.

252—MUD LOGGING

U. S. No. 2,423,774. J. J. Heigl. Iss. 7/8/47. App. 4/2/42. Assign. Standard Oil Development Co.

Oil Determination. A method of determining oil in samples by extracting with a

petroleum solvent, measuring the light absorption of the extract and comparing with the absorption of the pure solvent.

288—PRESSURE GAUGE

U. S. No. 2,423,394. L. Lee, II. Iss. 7/1/47. App. 12/30/43. Assign. Niles-Bement-Pond Co.

Device for Measuring the Ratio Between Two Variables. Apparatus for indicating the ratio of two pressures by applying each to a mercury manometer chamber the other side of which has a variable area and has a column of lighter liquid which rises to a height representing the logarithm, and using a differential pressure indicator between the two lighter liquids.

U. S. No. 2,427,249. G. C. R. Birch. Iss. 9/9/47. App. 6/5/44 and 9/14/44. Assign. B. & R. Patents Ltd.

Fluid Pressure Gauge. A differential pressure gauge having two opposing bellows whose common point deflects a spring rod.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,425,512. K. C. Crumrine. Iss. 8/12/47. App. 11/21/45. Assign. The Texas Co.

Measurement of Thickness. A radiation-transmission thickness-measuring method in which the point directly opposite the source is located by placing an absorber in line with the source and locating the shadow by moving the detector about.

U. S. No. 2,425,533. G. Herzog. Iss. 8/12/47. App. 11/21/45. Assign. The Texas Co.

Device for Measuring Wall Thickness. A gamma-ray detector for a radiation transmission-type wall-thickness measuring device having a number of anode wires passing through holes in plates, only one anode wire being connected to the indicator in locating the point opposite the source and all anode wires in making the transmission measurement.

U. S. No. 2,427,663. E. der Mateosian and M. McKeown. Iss. 9/23/47. App. 11/8/45.

Geiger-Mueller Tube. A penetrating radiation counter of long life and rapid counting response which has an atmosphere containing methylene bromide vapor.

312—RADIO NAVIGATION

U. S. No. 2,423,305. H. Fletcher. Iss. 7/1/47. App. 9/9/42 and 7/15/44.

Radio Navigation System. A radio navigation beacon having two spaced transmitters of different frequencies, one of which is modulated by a low frequency so that one sideband differs in frequency from one carrier by an amount equal to the frequency difference between another sideband and the other carrier so that each carrier and associated sideband may be segregated in a separate receiving channel.

U. S. No. 2,424,560. C. W. Earp. Iss. 7/29/47. App. 12/26/41 and 11/23/42. Assign. Standard Telephones and Cables Ltd.

Visual Course Indicator for Radio Directive Systems. A system for visually indicating course to an A-N type of radio beam in which the signals are rectified and applied to quadrature windings of a dynamometer-type indicator.

U. S. No. 2,425,008. G. T. Royden. Iss. 8/5/47. App. 2/3/44. Assign. Federal Telephone and Radio Corp.

Radio Navigational Apparatus. A glide-path airplane-landing system having a direction localizer beam of the A-N type, and a relay transmitter connected to a transmission line with distributed antennas along the ground for altitude control.

316—RADIO RANGING

U. S. No. 2,423,437. H. T. Budenbom. Iss. 7/8/47. App. 8/25/34. Assign. Bell Telephone Laboratories, Inc.

Direction Finder. A radio direction finder having an array of two non-directional antennas and a non-directional antenna at their mid-point all mounted on a turntable and in which a circular representation on a c.-r. tube screen of the signal from one end antenna is altered by the signal from the other end antenna at a point on the c.-r. trace depending on the phase relation of the signals.

U. S. No. 2,424,263. J. R. Woodyard. Iss. 7/22/47. App. 2/23/43. Assign. Sperry Gyroscope Co., Inc.

Radio System for Distance and Velocity Measurement. A distance-measuring system having an uhf transmitter and receiver giving a beat note when a moving object is encountered, and also a feed-back from receiver to transmitter which demodulates the beat note and modulates the transmitter to produce singing.

U. S. No. 2,424,984. R. B. Hoffman. Iss. 8/5/47. App. 2/14/42. Assign. Federal Telephone and Radio Corp.

Distance and Direction Radio-Object Detection. A radio-ranging system in which two antennas are alternately connected to a transmitter and receiver through transmission lines whose effective lengths are electronically varied to change the effective direction.

U. S. No. 2,425,383. D. G. C. Luck. Iss. 8/12/47. App. 5/31/43. Assign. Radio Corp. of America.

Radio Direction Finding. A radio direction finder which has a vertical dipole antenna revolving on the end of an arm and in which the resulting phase variation of the signal is observed by comparison with a local reference source.

U. S. No. 2,425,385. L. E. Norton. Iss. 8/12/47. App. 5/29/43. Assign. Radio Corp. of America.

Direction Finder. A radio direction finder which has a vertical dipole antenna revolving on the end of an arm and in which the resulting phase modulation of the signal is observed by locally generating an unmodulated carrier whose frequency is the same as the signal and a modulating signal the same as the signal modulation, and observing the relative phases of the signals when the phase modulations are opposite.

U. S. No. 2,425,386. L. E. Norton. Iss. 8/12/47. App. 5/29/43. Assign. Radio Corp. of America.

Direction Finder. A radio direction finder which has a vertical dipole antenna revolving on the end of an arm and in which the resulting phase modulation of the signal is observed by converting to a phase-modulated intermediate frequency, also generating a local modulated carrier of the same frequency and obtaining an intermediate frequency from it, and comparing the phases of the intermediate frequency signals.

U. S. No. 2,425,387. L. E. Norton. Iss. 8/12/47. App. 5/29/43. Assign. Radio Corp. of America.

Direction Finder. A radio direction finder which has a stationary non-directive antenna whose response is varied by revolving about it an auxiliary resonant antenna which modifies the picked-up field of the arriving wave.

U. S. No. 2,428,058. R. O. Wise. Iss. 9/30/47. App. 10/27/43. Assign. Bell Telephone Laboratories, Inc.

Object-Locating and Distance-Measuring Systems of the Pulse-Reflection Type. An automatic echo alarm for a radar system to attract attention when an echo is received.

324—RECORDER

U. S. No. 2,425,742. B. L. Kline. Iss. 8/19/47. App. 7/29/42. Assign. The Western Union Telegraph Co.

Electrosensitive Recording Blank. A facsimile-recording medium having a coating of a sulphur-containing organic compound of a metal which partially decomposes to a sulphide of the metal upon application of electrical potential.

U. S. No. 2,427,342. A. H. Andrews, Jr. Iss. 9/16/47. App. 6/8/45.

Meter-Indicator Photographic Recording Instrument. An attachment for the front of a pointer-type meter which photographically makes a continuous time record of the meter indications.

360—SEISMOGRAPH PROSPECTING

U. S. No. 2,423,970. L. W. Gardner. Iss. 7/15/47. App. 6/11/45. Assign. Gulf Research & Development Co.

Geophone Polarity Indicator. A system for indicating correctness of polarity of a geophone hookup by having a contact in the circuit close to the geophone moving element, applying a d.c. to the geophone line and detecting at the operator's cab a disturbance of the contact.

U. S. No. 2,427,421. F. Rieber. Iss. 9/16/47. App. 6/22/40.

Apparatus and Method for Making and Analyzing Geophysical Records. A system for analyzing seismograph records made as magnetic traces on a wide magnetic tape by scanning with reproducers placed along the radius of a disk which rotates in synchronism with the longitudinal movement of the tape so as to vary the angularity.

368—SEISMOGRAPH TIMING

U. S. No. 2,424,622. C. D. McClure. Iss. 7/29/47. App. 1/15/45. Assign. Socony-Vacuum Oil Co., Inc.

Timing Device for Recorders. A seismograph-record timer having a light-beam chopper on a vibrating reed which is released by an electromagnet at the beginning of the record, the electromagnet being subsequently used to generate current supplied to a galvanometer the peak of whose trace marks every other timing line.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,424,705. J. O. Parr, Jr. Iss. 7/29/47. App. 1/6/45. Assign. Olive S. Petty.

Seismic Surveying. A system of seimograph recording employing automatic gain-

control on the amplifier and in which the variation in gain is concurrently recorded on a separate trace.

376—SEISMOMETER

U. S. No. 2,423,591. J. W. Flude. Iss. 7/8/47. App. 9/16/39 and 3/7/42.

Apparatus for Making Geophysical Surveys Under Water. A seismometer for use under water which is towed into position by its cable and arranged with a float and fins so that it comes to rest on bottom in an upright position.

U. S. No. 2,424,724. J. F. Folk. Iss. 7/29/47. App. 7/27/45. Assign. Olive S. Petty.

Position-Dampened Seismometer. An electromagnetic geophone having an automatic switch which short-circuits the output leads whenever the instrument is positioned out of vertical so as to provide damping protection in transit.

U. S. No. 2,428,168. G. B. Loper. Iss. 9/30/47. App. 6/30/44. Assign. Socony-Vacuum Oil Co., Inc.

Seismic-Wave Detector. A mechanism for clamping a geophone to the side of a borehole by means of a spiked dog which catches in the opposite side of the hole and is controlled by an auxiliary rope or by momentary slacking of the supporting cable.

392—SIDE-WALL SAMPLER

U. S. No. 2,426,335. T. A. Banning, Jr. Iss. 8/26/47. App. 11/8/43.

Side-Wall Sampling Apparatus. A device having a side-wall sample cutter hydraulically operated from explosive gas pressure, the device also having electric connections for positioning with respect to a known electric log.

428—STRAIN GAUGE

U. S. No. 2,423,842. D. McHenry. Iss. 7/15/47. App. 2/28/46. Assign. U.S.A.

Protective Covering for Bonded-Wire Electric Strain Gages. A protective covering for a bonded-wire strain gage made by molding over the gage a rubber button sealed to the specimen being tested.

U. S. No. 2,423,867. C. M. Zener and D. M. Van Winkle. Iss. 7/15/47. App. 6/3/44.

Method and Apparatus for Stress-Strain Testing. A system for obtaining the stress-strain curve of a specimen in which an electrical strain gauge is mounted on the specimen and a similar one is mounted on the testing machine and their outputs amplified and applied to the horizontal and vertical deflecting plates of a c.-r. tube.

U. S. No. 2,426,396. H. D. Isenberg. Iss. 8/26/47. App. 2/21/45.

Force-Determining Device. An electric strain gauge in which the force changes the contact area between two crossed rods.

U. S. No. 2,427,866. W. D. MacGeorge. Iss. 9/23/47. App. 4/25/44. Assign. The Baldwin Locomotive Works.

Electromagnetic Motion-Responsive Device. An electromagnetic extensometer having three coaxial coils, the center coil being the primary, and a core slightly longer than the primary which is moved along the axis by a lever system.

U. S. No. 2,428,012. J. H. Collins and J. C. Nettles. Iss. 9/30/47. App. 8/22/42.

Torque Meter. A filament-type torque gauge having an insulating strip in the shape

of a 45° parallelogram with the filament wound at the 45° angle and mounted circumferentially on the torque shaft so that the wires make a 45° angle with the axis of shaft.

436—SUBMARINE SIGNALING

U. S. 2,423,119. J. B. Retallack. Iss. 7/1/47. App. 11/8/43. Assign. Bell Telephone Laboratories, Inc.

Hydrophone-Selecting System. A circuit having local relays and rectifiers for selecting from a central station one of a series of hydrophones along a connecting line.

U. S. No. 2,424,561. P. G. Edwards and D. D. Robertson. Iss. 7/29/47. App. 12/28/43. Assign. Bell Telephone Laboratories, Inc.

System for Locating the Source of an Explosion Wave. A practice attack meter in which the output of two pairs of quadrature microphones are separately amplified and stored in condensers whose charges are subsequently recorded in succession by automatic operation of a program switch, the wave direction being computed from the record.

U. S. No. 2,426,657. R. L. Williams. Iss. 9/2/47. App. 10/12/42. Assign. Submarine Signal Co.

Apparatus for Directional Signaling. A submarine-signaling microphone whose orientation is maintained by servo-motors controlled by a pendulum.

444—SURVEYING APPARATUS

U. S. No. Re. 22,919. (Orig. No. 2,320,290.) E. M. McNatt. Iss. 9/23/47. App. 8/8/41 and 5/24/44. Assign. Standard Oil Development Co.

Integrating Gradiometer. An apparatus for making elevation surveys consisting of a light source emitting impulses proportional to the distance travelled by a vehicle and transmitting to a photocell a fraction of these impulses proportional to the sine of the angle of inclination of the vehicle through a pendulum and shutter device, and counting the total number of light impulses received by the photocell.

460—THERMOMETER

U. S. No. 2,424,976. M. J. E. Golay and H. A. Zahl. Iss. 8/5/47. App. 6/12/39. Assign. U.S.A.

System for Detecting Sources of Radiant Energy. A thermal-radiation detector having an array of gas cells connected by tubes to parts of a thin diaphragm whose distortion is observed by an optical-interference method.

U. S. No. 2,426,494. J. Evans. Iss. 8/26/47. App. 12/20/43. Assign. Radio Corp. of America.

Heat-Detection Device. A heat-sensitive detector made by evaporating on a cellulose acetate film a semiconducting film of tellurium oxide and evaporated gold contacts.

468—TIME-INTERVAL METER

U. S. No. 2,424,773. F. Rieber. Iss. 7/29/47. App. 2/26/44. Assign. Interval Instruments, Inc.

Locating Device. A sound-ranging apparatus in which the microphone signals are magnetically recorded on endless tapes or disks so that they may be played back repeatedly for analysis to determine the direction to the sound source.

U. S. No. 2,426,910. W. S. Wilson. Iss. 9/2/47. App. 1/27/44. Assign. Radio Corp. of America.

Measurement of Time Between Pulses. A time-indicating circuit for a pulse-echo system in which the starting pulse and the final pulse are converted to saw-tooth form and applied in phase opposition to a meter.

484—TRANSDUCER

U. S. No. 2,423,208. C. M. Sinnett. Iss. 7/1/47. App. 5/30/44. Assign. Radio Corp. of America.

Electrostatic Pickup. A capacity-type reproducer in which the stylus is made of two metal parts separated by a thin layer of rubber to provide a variable-capacity condenser.

U. S. No. 2,423,662. B. Roberts. Iss. 7/8/47. App. 9/8/44. Assign. Philco Corp.

Phonograph Pickup Device. A variable-area reluctance-type phonograph pickup in which the stylus moves an armature transversely to the axis of magnetic pole pieces.

U. S. No. 2,423,922. J. P. Arndt, Jr. Iss. 7/15/47. App. 1/11/43. Assign. The Brush Development Co.

Piezoelectric Transducer. A method of fabricating a multiplate crystal transducer by applying a thermo-plastic cement to a strip of electrode material which is wide enough to extend beyond the crystal and passing a heating current through the electrode material while the assembly is under pressure.

U. S. No. 2,426,061. R. Snepvangers. Iss. 8/19/47. App. 11/21/44. Assign. Radio Corp. of America.

Electric Phonograph Pickup of the Capacity Type. A capacity pickup in which the stylus is carried on a flexible condenser plate which in turn is supported by a flexible strip in a plane at right angles to that of the plate.

U. S. No. 2,426,396. H. D. Isenberg. Iss. 8/26/47. App. 2/21/45.

Force-Determining Device. An electric strain gauge in which the force changes the contact area between two crossed rods.

U. S. No. 2,427,062. F. Massa. Iss. 9/9/47. App. 6/2/44. Assign. The Brush Development Co.

Vibrational Energy Transmitter or Receiver. A piezoelectric transducer having a piston whose parts are driven at different amplitudes in order to improve directivity.

U. S. No. 2,427,348. W. L. Bond and W. P. Mason. Iss. 9/16/47. App. 8/19/41. Assign. Bell Telephone Laboratories, Inc.

Piezoelectric Vibrator. A piezoelectric vibrator in which internal reflection is minimized by interposing between the crystal and the medium one or more materials whose acoustic impedance is the geometric mean of the acoustic impedances on each side of it.

492—VIBROMETER

U. S. No. 2,424,864. R. C. Treseder. Iss. 7/29/47. App. 5/2/44.

Vibration-Responsive Apparatus. A vibrating-reed type of vibration meter using two adjustable reeds differing slightly in resonance and having electric pickup coils on each reed connected in series to an indicating meter.

496—VISCOSIMETER

U. S. No. 2,426,263. K. Fischer. Iss. 8/26/47. App. 5/15/44.

Viscosimeter. A device for determining viscosity of fluids in motion and which has two rotameter floats, one of which is sensitive only to rate of flow and one sensitive to both rate and viscosity, the difference in positions of the two floats indicating the viscosity.

U. S. No. 2,426,393. K. Fischer. Iss. 8/26/47. App. 1/24/45. Assign. Fischer & Porter Co.

Viscosimeter. A device for determining viscosity of fluids in motion which has two rotameter floats, one of which is sensitive only to rate of flow and one sensitive to both rate and viscosity, the position of the first float being adjusted to an index and viscosity read directly from the position of the second float.

508—WATER LOCATING

U. S. No. 2,426,730. A. De Vita. Iss. 9/2/47. App. 2/26/45 and 9/11/45.

Process for the Artificial Creation of Accumulations of Subterranean Courses of Water. A system for storing rain water underground by drilling a well to a permeable formation, surrounding it with catch ditches and filters, and removing the water through another well down dip in the permeable formation.

512—WELL SHOOTING

U. S. No. 2,428,168. G. B. Loper. Iss. 9/30/47. App. 6/30/44. Assign. Socony-Vacuum Oil Co., Inc.

Seismic-Wave Detector. A mechanism for clamping a geophone to the side of a borehole by means of a spiked dog which catches in the opposite side of the hole and is controlled by an auxiliary rope or by momentary slacking of the supporting cable.

520—WELL SURVEYING

U. S. No. 2,425,319. D. Hering. Iss. 8/12/47. App. 12/23/42. Assign. Sperry-Sun Well Surveying Co.

Tool-Orienting Method and Apparatus. A whipstock-orienting device which carries a magnet on the whipstock and also a magnet on an inverted pendulum and has a motor to rotate coils opposite these magnets the impulses being transmitted to the surface and used to light a rotating neon lamp which stroboscopically illuminates a compass rose.

U. S. No. 2,425,868. L. Dillon. Iss. 8/19/47. App. 8/28/36. Assign. Union Oil Co.

Method and Apparatus for Logging Drill Holes. A method of logging or surveying in which the parameter logged is converted into mechanical vibrations whose frequency is related to the parameter and the vibrations picked up at the surface and indicated on a frequency meter.

REVIEWS

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Report on Activities of the Associate Committee on Geodesy and Geophysics of the National Research Council of Canada for April 1 through June 30, 1947. (30 pages)

This report is one of the results of a meeting of the Associate Committee on Geophysics of the National Research Council of Canada held January 23, 1947. The report of this meeting was reviewed in the April, 1947, issue of GEOPHYSICS. The current report may be considered a progress report for the various sections comprising the Committee for the period mentioned. It also contains a bibliography pertinent to each section. At present such disciplines as seismology, vulcanology, terrestrial electromagnetism, geodesy and gravity, tectonics, meteorology, oceanography, and several others are included.

Although in the original report of this Committee hydrology, meteorology, vulcanology, and oceanography were not represented, a considerable portion of this report is devoted to the proposed plan to conduct various types of research in these fields. The proposed program in the field of oceanography appears to be quite diversified and the results of several of the projects should be of interest to geophysicists and geologists. A partial list of proposed projects includes: (a) a geologic survey of the oceans through an analysis of core samples of the ocean bed, (b) a survey and mapping of the physical nature of the ocean floor of Canadian coastal areas, and (c) a survey of the physical and chemical characteristics of the Atlantic, Pacific and Arctic waters.

A coordinated attack, using five geophysical methods, is currently under way in an attempt to delimit the major structural characteristics of a portion of Ontario situated approximately between Sudbury and Kirkland Lake. The geophysical methods employed include gravity, magnetic, seismic, radioactivity, and geothermal surveys. In addition, an airborne magnetometer survey has been proposed.

Magnetic.—One of the three U. S. government airborne magnetometers secured by the Mines and Geology branch, Department of Mines and Resources, and the Division of Physics, N.R.C., was installed in an Anson plane and preliminary trial flights were completed. A number of small magnetite deposits lying between Arnprior and Kingston will be flown to test the equipment. A region near Ottawa in which faults affecting both Pre-Cambrian and Paleozoic rocks are mapped will be surveyed subsequently. The plane will then probably be sent north to a mining area. A number of commercial contract crews have been operating in various areas using magnetic and electric methods. The methods and results are described in some detail.

Geodesy and Gravity.—The establishment of an extensive triangulation network in the Gulf of St. Lawrence loop has necessitated measuring new base lines and occupying Laplace azimuth stations to reduce scale and twist errors. The net extends from the Strait of Belle Isle along the north shore of the Gulf of St. Lawrence to Anticosti Island, thence across the mouth of the St. Lawrence River to Gaspé and then southerly and easterly through Quebec, New Brunswick and Nova Scotia, then northeasterly across Cabot Strait and northerly along the western coast of Newfoundland to the Strait of Belle Isle. The closure of the 1,400-mile loop was 34.5 feet representing a ratio error of

1/214,000. Additional information regarding the details of the Newfoundland section of the loop may be found in Publication No. 64 of the Geodetic Survey by C. H. Ney.

Field parties of the Geodetic Service also established additional base lines and conducted precise leveling, triangulation, and Laplace azimuth surveys in different parts of Canada. In addition, astronomic ground control for areal mapping in the area west of Hudson Bay between latitude 66° North and the Arctic coast was established in this area as well as in two other regions.

The Dominion Observatory has included plans for establishing 200 gravity and magnetic stations in portions of the Pre-Cambrian Shield in the northern areas of Ontario, Manitoba and Saskatchewan. A Norseman aircraft was chartered for use in this survey. A number of short traverses were made in New Brunswick in connection with geologic deposits of economic interest. A vertical-component Askania magnetometer also was used in this survey which represents a continuation of similar surveys begun last summer.

Tectonics.—The section on tectonics reported on the results of the symposium on the structural relations of Canadian ore deposits. This symposium is to be published by the Canadian Institute of Mining and Metallurgy in time for their 50th annual meeting in April, 1948. The 130 papers comprising this volume of 800 pages will consist primarily of descriptions of the structural and economic geology of individual properties. However, three papers are also included which deal with the general geology of three major regions: the Cordillera, the Canadian Shield and the Appalachians.

Radioactivity.—The radioactivity of approximately 6,500 specimens of North American rocks were determined by Dr. Keevil and his associates. The results of this work will be prepared for publication and the project itself is still under way. An additional 600 specimens were collected this summer in the Sudbury and Kirkland Lake districts of Ontario. They will be used to correlate the heat given off by the measured radioactive contents of these rocks with the heat flow observed in Ontario mines. The age of selected specimens will be determined by measuring the ratio of helium to radioactive elements.

R. A. GEYER

Seismic Measurements on the Ross Shelf Ice by Thomas C. Poulter, Transactions American Geophysical Union Part I. Vol. 28, No. 2 pp. 162–170, April 1947. Part II, Vol. 28, No. 3, pp. 367–384, June, 1947.

When the second Byrd Antarctic Expedition left for the South Polar regions in 1933, it took along a specially designed seismograph and other equipment necessary for a reflection survey to determine the nature and thickness of the Ross Shelf ice. Dr. Thomas C. Poulter, Chief Scientist and second-in-command of the expedition was in charge of the survey. The results obtained are highly significant and are indicative of the power of the geophysical techniques developed in the search for petroleum to answer fundamental questions which have puzzled generations of explorers, geographers or geologists.

Few seismic crews anywhere have had to operate under the difficulties that faced Poulter and his party of four men who traveled 1,000 miles by dog team and 1,000 miles by plane over the rough and barren ice of the Ross Shelf. The equipment had to be designed keeping in mind the limitations that their unique form of transportation would impose. A major problem involved mounting the recording equipment so that it could be made snowtight in the event of a sudden blizzard while the party was on the trail. Two sleds were used, one for the seismic equipment and the other for emergency camping and navigating gear in case of a blizzard. Special explosives dependable at very low temperatures were required because of the climate. The shot holes were drilled by hand

augur, the charges buried 6 feet in the ice, with the geophones placed 2 feet below the surface.

The standard spread consisted of four geophones 200 feet apart with shots 1,800 feet apart on each side of the group. Bearings of each shot location were determined from photographs made in an aerial survey of the Bay of Whales region. Sensitivities were adjusted "making use of the vibrations produced by the assistant operator skiing back past the geophones." Shots were fired "after making sure that the dogs were all quiet." Records were not developed until return to the base camp.

Reflections were obtained from (1) the bottom of the ice layer; (2) the bottom of the water on which the ice was floating (where it was not grounded); (3) the solid rock bottom at the base of the morainal rock underlying most of the shelf ice; and (4) in many cases from minor interfaces within the moraine. By correlating reflections Poulter was thus able to map the depth of the sea under the ice, the thickness of the ice and the depth to bed rock under most of the Bay of Whales section of the Ross Shelf Ice.

The most spectacular result, according to the author, was the discovery that the topographic rise in the ice southeast of Little America actually covers an island long suspected but never before proved, 90 miles long and 40 miles wide. West of this the ice is grounded on a moraine surface somewhat below sea level, extending out over the water of the Ross Sea for ten miles north of the moraine's northern edge.

It is unfortunate that in these papers Poulter leaves out all discussion of the reduction and interpretation techniques by which he arrived at his results. Even a reproduction of a sample record would have served to demonstrate to the reader the quality of the reflections from which the depths were derived. An account of how the velocity of sound was measured in the shelf ice would be very desirable. A footnote in the table indicates that three stations were occupied for the purpose of determining the velocity of sound in the ice. It is therefore presumed that some method similar to the (T^2-d^2)-technique was employed. The determination of speeds in the morainal material below the ice must have presented a more serious problem but there is no mention of how this was attacked. However, it is understood that the author intends to publish further on the subject of his interpretation methods.

Although two maps showing shot-point location accompany the papers, it is difficult for the reader to correlate the two and obtain a clear picture of where the work was done. The two cross sections are highly instructive, but one of them gives a detailed representation of a thirty-mile profile on the basis of actual data at only three stations.

The information the seismograph has given on the thickness and configuration of the shelf ice is especially valuable in answering questions concerning the origin of the ice, the reason for the tide cracks, the equilibrium and persistence of the present ice boundaries, and other matters of primary interest to the glacial geologist. Poulter discusses these questions at some length in the light of his findings.

In recent years structural geologists, such as Bucher, have come to realize that the cracks and folds observed in the great ice sheets such as those in Greenland and Antarctica are accurate dynamic models of similar deformations that have been occurring throughout geological time in the earth's crust. For them, the information Poulter now provides on the thickness, density and support of the Ross ice should make the analogy even more fruitful and more subject to quantitative analysis and application to the earth's crustal structures.

MILTON B. DOBRIN

Pulse of the Earth, by J. H. F. Umbgrove. The Hague—Martinus Nijhoff—1947.

There are too few books of this type available in English. Not since the appearance of the translation by Sollas of Suess' book "Das Antlitz der Erde" (1909) has a com-

parable one appeared; although Bucher's "Deformation of the Earth's Crust" (1933) and Daly's "Strength and Structure of the Earth" (1940) deal with similar topics but not as extensively. Books of comparable character but not written in English include:

Stille, H., *Grundfragen der Vergleichenden Tektonik*, 1924.
Bubnoff, S. von, *Grundprobleme der Geologie*, 1931.
Kossmat, F., *Palaeogeographie und Tektonik*, 1936.

Umbgrove's book contains a very competent synthesis and evaluation of all the more provocative hypotheses found in the literature of regional geology, geophysics, and tectonophysics from the time of Suess to the present day. "The Pulse of the Earth" can be used to good advantage not only by students in these fields but also as a reference book for those who have long been engaged in such activities.

The salient ideas of prominent contributors to the progress of earth sciences such as Barrell, van Bemmelen, Born, von Bubnoff, Bullard, Cloos, Daly, Du Toit, Ewing, Gerth, Grabau, van Waterschoot van der Gracht, Griggs, Gutenberg, Heiskanen, Hess, Hobbs, Holmes, Kossinna, Kossmat, Krenkel, Kuenen, Rutten, Schuchert, Shepard, Smith, Stetson, Stille, Umbgrove, Vening Meinesz, Wegener, Willis, and many others are made available for analysis and comparison in a single volume. Because of the broad scope of this work, no attempt will be made to present a systematic review. Instead, a list of the main chapter headings is included and brief mention made of some of the topics which are of particular significance at this time. The extensive bibliography which includes more than 600 references is especially valuable because for the first time many of the more important references dealing with the earth sciences which appeared in foreign periodicals and books during the war years appear and are discussed in one book. Although the majority of the 204 illustrations are taken from the original authors, many of them represent a synthesis of ideas and material as presented by the author. In addition to these figures, eight colored plates are also included. They deal primarily with the representation of various world-wide orogenic epochs for different geologic ages, as well as with the global distribution of major sedimentary basins.

Chapter headings are: "Space and Time," "Mountain-Chains," "Basins and Troughs," "Crust and Substratum," "Oscillations of the Sea-Level," "The Continental Margin," "Island-Arcs," "The Floor of the Oceans," "Ice-Ages," "The Rhythm of Life," "Linear Patterns," and "The Pulse of the Earth." The chapters dealing with the continental margin and island arcs are of particular interest at the present time. A classification and description of various hypotheses pertaining to the origin of submarine valleys are especially well done. The geophysical factors involved in the study of the continental margins, with particular reference to gravity and the effect of periodic convection currents, are described in some detail including many illustrations from the works of Shepard, Smith, Stetson, Bullard and Ewing. The contributions of Hess, Meinesz, Umbgrove, and Kuenen to the problem of the origin of island arcs occupy a major portion of this chapter. The concept of a double arc found particularly in the East Indies is postulated by the author and discussed in some detail. The companion chapter devoted to the floor of the oceans also makes interesting reading. In this chapter the controversial problem of continental drift is summarized remarkably well; this includes a schematic representation of three groups of hypotheses dealing with the formation of continents and oceans by Suess, Haug, Wegener, and Du Toit. Umbgrove does not come to any definite conclusion during his discussion of the problem and leaves the door open for further conjecture in the light of future information.

Some of the more interesting and provocative illustrations include:

(a) a schematic review of four major types of structural basins,
(b) a cross section of a hypothetical continent in which changes with depth of various physical characteristics are illustrated,

TABLE OF GEOLOGIC AGES

Helium Ages of Magnetites in Millions of Years After Evans, Goodman and Keevil A.[b] 1942–1944	Revised Helium Time Scale in Millions of Years After Urry and Holmes A.° 1941	Helium Time Scale After Holmes A.° 1937	Stratigraphic Column of Table II	Lead Time Scale: After Holmes A.° 1937	Lead Time Scale: After Evans and Goodman A.° 1944	Lead Time Scale: After Holmes A.° 1946	Cumulative Maximum Thickness of Strata Plotted Against Ages from Lead Ratios (Holmes A.° 1946): Stratigraphic Column	Ages	Max. Thickness in Thousands of Feet	Cumulative Maximum Thicknesses
	Pliocene 8	13	Pliocene				Pliocene	16	4	4
	Miocene 10	18	Miocene						18	22
	Oligocene 20	32	Oligocene } Tertiary	35	34		Miocene	32	21	43
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	Devonian 180	175					Triassic			
			Permian				Permian	196	25	190
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			Carboniferous		240					
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		292	Devonian	278	278	280	Devonian	274	40	248
Carboniferous 300 Devonian 316			Silurian		333		Silurian	322	37	285
		—345—								
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Devonian? {366 396		365	Ordovician	366 371	341–361 371 388		Ordovician			
				395 405						
		427						428	40	345
		453	Cambrian			440	Cambrian			
	Keweenawan {485 520–525		Precambrian		531			508	40	385

(c) a series of four tentative schematic block diagrams illustrating the relationship between tectonic and magmatic cycles,
(d) a comparison cross section of the Monterrey submarine canyon with the Grand Canyon,
(e) a diagram to illustrate the distribution on the surface of initial dilation and compression of earthquake shocks caused by a deep-focus earthquake,
(f) a series of five schematic sections showing tentatively the development of a double island arc and a schematic diagram of an East Indies type double island arc,
(g) a tentative interpretation of a subcrustal crowding of sima in the concave side of an island arc and the origin of plutonism and vulcanism in the inner arc,
(h) a series of seven illustrations depicting the position of ice sheets, glaciers and tillites during various geologic periods,
(i) a quantitative interpretation of the cooling power of an ice cap,
(j) a series of two figures representing changes in mean temperature and pressure with increase in relative sun-spot numbers,
(k) a figure showing the hypothetical reconstruction on a global scale of geographic conditions during the Upper Paleozoic ice ages,
(l) a world map showing the shearing net based on the assumption of a displacement of the North Pole from near Calcutta over 70° along the 90° east-longitude meridian (taken from one of Vening Meinesz's more recent articles dealing with this subject).

One of the more interesting tables found in this volume in the form of a tabulated comparison of different methods used in the determination of geologic ages is reproduced in this review in its entirety. It serves as an example of the excellent manner in which the author throughout the entire book has synthesized various sources of information relating to a given problem.

The need for additional books of this type from time to time, when the accumulation of sufficient diversified information from the earth sciences permits, is perhaps best demonstrated by a quotation from the concluding chapter of this book:

"Nevertheless, the mysterious interior of the earth involves more than just a single periodic process. It is far more complicated than the tentative theories have supposed so far. I hope that the preceding chapters and the accompanying graphs will have made this clear. Geology will have to proceed hand in hand with geophysics in a combined effort to unravel this most absorbing problem. A solution will only be found when it will be possible to indicate that a logical and necessary correlation of cause and effect exists between certain events in the earth's interior and those diverse phenomena to which I referred briefly in the title as 'The Pulse of the Earth'."

R. A. GEYER

PUBLICATIONS RECEIVED

Arrangements have been made with the University of Tulsa Library to act as a repository of publications received by the Society. Members desiring to borrow any of these publications should address a written request to the Business Manager, Mr. Colin Campbell, P. O. Box 1614, Tulsa, Oklahoma.

American Journal of Science, Vol. 245, No. 10 (October, 1947) and No. 11 (November, 1947).

Economic Geology, Vol. 42, No. 6 (September–October, 1947).

Geofisica Pura e Applicata, L'Instituti Geofisico Italiano. Milano Vol. X, Fasc. 3-4, 1947.

Institute of Petroleum Review, Vol. 1, No. 9 (September, 1947) and No. 10 (October, 1947).

Journal of Applied Physics, Vol. 18, No. 9 (September, 1947), No. 10 (October, 1947), and No. 11 (November, 1947).

Journal of the Institute of Petroleum. Vol. 33, No. 284 (August, 1947), No. 285 (September, 1947), and No. 296 (October, 1947).

Mitteilungen aus dem Institut fur Geophysik, Edigenossische Technische Hochschule Zurich, No. 5 (December, 1946) No. 6 (June 1947), No. 7 (June 1947), No. 8 (September, 1947).

Nafta ("Petroleum"), Petroleum Institute of Poland, Krakow. Rok III, Nr 9 (September, 1947), Rok III, Nr 10 (October, 1947).

Nr 10. "Geological Structure of Magura Overlap in Mecina Wielka Region," by Kenryk Kozikowski.

"Transportable Drilling Rigs for Wildcatting," by Zbigniew Wyszynski.

Proceedings of the Cambridge Philosophical Society, Vol. 43, Part 4 (October, 1947). "On the Geometry of the Wave Equation," by A. G. D. Watson, p. 491.

Quarterly Journal of the Geological Society of London, Vol. 103, Part 1 (August, 1947).

Review of Scientific Instruments, Vol. 18, No. 10 (October, 1947), No. 11 (November, 1947).

Terrestrial Magnetism and Atmospheric Electricity, Vol. 52, No. 3 (September, 1947).

World Petroleum, Vol. 18, No. 12 (November, 1947).

Reprints:

Alfredo Castellanos. "La Presencia Del Genero BOREOSTRACON Simpson en Uraguay y Brasil." Publicaciones del Instituto de Fisiografia y Geologia, Rosario, Argentina.

RUSSIAN GEOPHYSICAL BOOKS

1. V. N. Dakhnov. Well Logging. Interpretation of logs. The most complete, authoritative and exhaustive treatise on logging. 1941.
2. L. M. Alpin. Theory of electrical well logging. 1938.
3. M. F. Mirchink. Petroleum Production Geology. 1946.
4. English-Russian Geophysical Dictionary. 1947.
5. Transactions of the Institute for Applied Geophysics (NIIPG). Applied Geophysics. Collection of papers N 1. 1945.

Contents

1. V. S. Voiutsky. Schematic diagrams of geophones group connections.
2. V. N. Roudnev. Determination of reflecting planes with the method of time gradients.

3. N. N. Pouzierev. Determination of the reflecting interface with consideration of refraction at an intermediate oblique interface.
4. V. N. Roudnev. Calculation of mean velocities from apparent velocities.
5. N. N. Puozierev. Determination of mean velocity from the hodographs of reflected waves.
6. In. V. Riznichenko. Application of the "fields of times" method in practice.
7. A. A. Tsvetaev. Application of air blasts in reflection prospecting.
8. A. A. Tsvetaev and N. I. Shamirovsky. Marine seismic work at Apsheron peninsula.
9. L. M. Alpin. The separation of measuring electrodes in electrical prospecting.
10. S. G. Komarov. Apparent resistance of layers having finite thickness and high resistivity.
11. S. G. Makover. Determination of torsion balance data by means of the method of least squares.
12. J. D. Boulanger. Some problems on gravimetric surveying.
13. I. A. Balaboushevich and O. P. Gratsianova. Geophysical prospecting in the southwest part of Volge-Ural oil district.
14. A. A. Borisov and G. T. Krouglikova. Gravimetric and magnetic measurements in Western Siberial lowland.

6. Transactions of the Institute for Applied Geophysics (NIIPG) Applied Geophysics. Collection of papers no. 2. 1945.

Contents

1. I. K. Koupalov-Iaropolk. Prospecting of areas between salt domes in the Emba Oil District.
2. M. C. Molodenski. Spring-gravimeter.
3. L. M. Alpin. Calculated electrode spacing.
4. L. M. Alpin. Screening surfaces.
5. A. A. Korzhev. Thyratron switch.
6. N. N. Puzieriov. Radial diagrams under arbitrary conditions of variation of velocity in the depth.
7. O. A. Shvank. Fundamentals of magnetic field of layer.
8. L. M. Alpin. Influence of unhomogeneities of intermediate zones on the electrical logs.
9. S. G. Komarov. Influence of galvanic corrosion on the self potential logs.
10. S. G. Komarov and V. V. Snitkin. Echometer with mechanical registration.
11. J. D. Boulanger. Some attainments in gravimetry abroad.

7. Transactions of the Institute for Applied Geophysics. (NIIPG) Applied Geophysics. Collection of papers no. 3. 1947.

Contents

1. S. M. Sheinman. Establishing of electromagnetic fields in earth.
2. L. M. Alpin. Field Sources in electrical prospecting.
3. V. N. Golovtzin. Combined field in electrical prospecting.
4. A. A. Datzkevitch. Design of a geophone.
5. M. L. Anlokolski. Distortion of a seismic impulse by a recording channel.
6. V. A. Bugailo. Determination of average speed by the method of sum difference and constant difference.
7. A. E. Khromoi. Gravimetric Survey of Complicated Reliefs.
8. S. E. Subbotin. Utilization of Curvature in Gravimetric Interpretation.
9. O. A. Shvank. Density of Rocks in the District of Buguruslan.

10. L. M. Rozanov. Relationship Between Density and Tectonic Characteristic of Rocks in the District of Buguruslan.
11. L. N. Rosanov and V. V. Maziuk. Corrections of geological maps involving results of electrical prospecting in the Buguruslan oil district.

8. The Bulletin of the Academy of Sciences of the USSR Vol. X, No. 1. Series Geographical and Geophysical. 1946.

Contents

1. L. S. Leibenson. To the theory of motion of an aerated liquid in a porous medium.
2. G. A. Gamburtsev. On the representation of seismic fields.
3. G. A. Gamburtsev. Correlation systems of observations in prospecting by the methods of reflected and refracted waves.
4. G. A. Gamburtsev. On waves caused by a moving source in a solid elastic medium.
5. G. V. Riznichenko. The three dimensional problem of the interpretation of the reflection time-curves.
6. T. S. Berson. The interpretation of surface time-curves of reflected waves.
7. T. S. Berson. To the solution of the direct problem of the method of refracted waves for continuous media with boundaries of discontinuity.
8. T. P. Kosminskaya. On the initial points of the time-curves of Mintrop's waves.
9. A. M. Epinatyeva. On the time-curves of reflected waves in the case of a vertical gradient of velocity.
10. V. G. Gogoladze. On the propagation of electromagnetic waves in different media adjoining each other along a plane.

9. The Bulletin of the Academy of Sciences of the USSR Vol. XI, No. 1. 1947.

Contents

1. L. T. Rubinstein. On the solution of Stefan's problem.
2. V. G. Afanasieva. The spherical harmonic analysis of the geomagnetic field for the epoch 1945.
3. N. E. Malinina. The magnetic field of West Siberia.
4. B. A. Andreyev. Calculations of the spatial distribution of potential fields and their application to prospecting geophysics.
5. U. P. Boulashevich. Diffusion of emanation in the soil with account of convection.

10. The Bulletin of the Academy of Sciences of the USSR Vol. XI, No. 2. 1947.

Contents

1. G. V. Riznichenko. Seismic velocities in stratified media.
2. N. T. Nikolayer. Fundamental ideas of the newest tectonics of the Russian platform.
3. A. G. Tarkhov. On the relation of the dielectric constants of rocks to their mineralogical composition.

11. The Bulletin of the Academy of Sciences of the USSR Vol. XI, No. 3. 1947.

Contents

1. T. S. Berson. On the choice of the longest possible time-curves of reflected waves.
2. J. D. Boulanger. Dynamic Temperature correction for invar pendula.

12. The Bulletin of the Academy of Sciences of the USSR Vol. XI, No. 4. 1947.

Contents

1. G. V. Riznichenko. Transformation of media in geometrical seismology.
2. A. F. Lisjutin. On measurement of the velocity of sound in oil wells.

13. Transactions of the Institute for Theoretical Geophysics Vol. I. 1946.

Contents

1. A. N. Tikhonov. Electrical prospecting over an inclined bed.
2. R. T. Turkisher. Calculation of the field of a point source over an inclined bed.

14. Transactions of the Institute for Theoretical Geophysics Vol. II. 1946.

Contents

1. G. V. Riznichenko. Geometrical seismology of stratified media. In the present paper the consideration of the fundamental problems is given concerning the interpretation of time-curves got by seismic prospecting with the aid of main modern methods: the reflection method, the refraction method (especially the new correlation method), and the method of seismic observations using deep wells (especially the well detector method).

15. Transactions of the Moscow Petroleum Institute—Issue No. 4. 1946.

Contents

1. V. N. Dakhnov. pp 101, Relationship between filteration potentials and permeability of rocks.

16. V. A. Sokolov. Modern methods of geochemical prospecting for oil and gas (booklet). 1945.

CONTRIBUTORS

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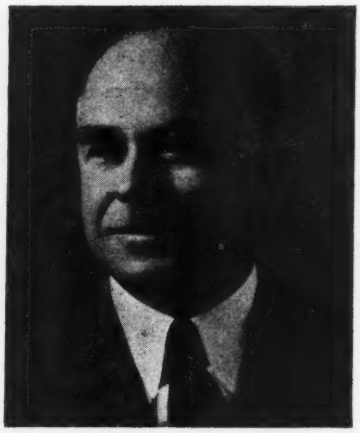
FRANK ITTNER received the degree of B.S. in Mechanical Engineering at the University of Oklahoma in 1933. After leaving school he was employed for a year by the Slick-Urschel Oil Company in the Oklahoma City Oil field as a combination roustabout and general flunky. The next two years were spent on the computing staff of a Geophysical Research Corporation seismic crew operating in Oklahoma and the Gulf Coast regions. Since 1936, he has been employed by the Superior Oil Company of California where he is presently Chief Seismologist of their Pacific Division.

He is a member of Tau Beta Pi, Sigma Tau, Sigma Gamma Epsilon, Society of Exploration Geophysicists, and the American Association of Petroleum Geologists.

CURTIS H. JOHNSON was graduated from the University of California at Los Angeles in 1932 with an A.B. and Honors in Physics, and took postgraduate work in acoustics, also at U.C.L.A. From 1933 to 1938, he was Geophysicist and later Chief Geophysicist with Rieber Laboratory. From 1939 to the present date, he has been Geophysicist with the General Petroleum Corporation.

Mr. Johnson's papers have been published in GEOPHYSICS and the *Bulletin* of the A.A.P.G. He is a registered Patent Agent, and holds patents in the fields of magnetic core orientation and bore hole drilling. He is a member of the American Association of Petroleum Geologists, the American Geophysical Union, and the Society of Exploration Geophysicists.



CURTIS H. JOHNSON

O. C. LESTER, JR.

O. C. LESTER was graduated from the University of Colorado in 1923 with an A.B. degree in Physics. After graduation, he spent one year at the Western Electric Company in Chicago in the Development Engineering Branch and at the same time did graduate work in Physics at the University of Chicago night school. He returned to the University of Colorado 1924–25 for further graduate study and teaching.

Mr. Lester entered the employ of Gulf Refining Company in 1925 at Houston, Texas, from 1925–31 worked in the Gulf Coast region and Mexico, and from 1932–33 in California. In 1933, he joined the Amerada Petroleum Corporation at Tulsa, and from 1943 to the present time, has been with Amerada in California.

He is a member of Sigma Xi, the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, the American Geophysical Union, and in addition, helped organized the Society of Petroleum Geologists in Houston in 1930.

PATRICK E. HAGGERTY

PATRICK E. HAGGERTY received the degree of B. S. in Electrical Engineering from Marquette University in 1936. He was employed as a student engineer by Globe-Union, Inc. in their storage battery and spark plug division. From 1936 to 1942, he was with Badger Carton Company of Milwaukee as Assistant General Manager, leaving to accept a commission in the Naval Reserve. During most of the war, Mr. Haggerty was attached to the Navy's Bureau of Aeronautics in Washington, D. C., acting finally as head of the Electronics Production Branch. In November, 1945, he joined Geophysical Service, Inc. and is now General Manager of G.S.I.'s Laboratory and Manufacturing Division.

He is a member of the Society of Exploration Geophysicists, Institute of Radio Engineers, the American Geophysical Union, American Association for the Advancement of Science, Society for Applied Anthropology, the Navy League, Tau Beta Pi, Alpha Sigma Nu, and Sigma Phi Delta.

BENO GUTENBERG

BENO GUTENBERG is Professor of Geophysics at the California Institute of Technology. He was trained in Germany receiving his Ph.D. from the University of Göttingen. During the period of 1924–1930, he taught geophysics at the University of Frankfurt, and at the same time, wrote his well-known text book *Lehrbuch der Geophysik* and served as editor of the ambitious project *Handbuch der Geophysik*, several volumes of which have been published. In 1930, he was invited to the California Institute of Technology to assume his present position as Director of the Seismological Laboratory and professor of geophysics.

RAÚL F. HANSEN was born at San Pedro (Buenos Aires), Argentina, March 1, 1914. He was graduated with a degree in Civil Engineering from the Universidad del Litoral in 1940. In 1941, he began work in Y.P.F. (Argentine Government Oil Field), and the same year received the title of Geophysics Engineer in the Instituto del Petroleo of the University of Buenos Aires.

During 1942, he was helper engineer of the crew, and from then until the present time, party chief.

RAÚL F. HANSEN

THEODORE P. ELLSWORTH received the degree of Bachelor of Science in Industrial Engineering from the Sheffield Scientific School of Yale University in 1930. Prior to his graduation he worked one year in the Division Engineers' office of the New York, New Haven and Hartford Railroad at Hartford, Connecticut. From 1930 to 1935, he was associated with his family in various business enterprises in Connecticut. The next year was spent as a bridge design engineer for the Connecticut State Highway Department. In 1936, he accepted a position with Western Geophysical Company in California, remaining with them until 1943; the last five years as party chief. Since 1943, he has been in charge of Richfield Oil Corporation's geophysical exploration. He is a member of the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, and the American Geophysical Union.

T. P. ELLSWORTH

R. W. OLSON

R. W. OLSON received the degree of B.E.E. from the University of Minnesota in 1938. From 1938 through 1940 he was employed by Magnolia Petroleum Company with a seismic field party and in their laboratory. In 1940, Mr. Olson joined the Naval Ordnance Laboratory where he was in charge of measurements in the field, and later, several projects in the laboratory. In 1942, he was transferred to the Bureau of Aeronautics, Engineering Division, as a project engineer on a number of electronic equipments. Mr. Olson joined Geophysical Service, Inc., in 1945 where he is at the present time.

CHARLES HEWITT DIX

CHARLES HEWITT DIX received his B.S. degree in Physics from the California Institute of Technology in 1927, and his Ph.D. in Mathematics from the Rice Institute in 1931. He was an Instructor in Mathematics at Rice from 1929 until 1934, when he became associated with the Humble Oil and Refining Company as a research geophysicist. In 1939, he became geophysicist for the Socony-Vacuum Oil Company, handling the research aspects of foreign geophysical exploration. From September, 1941, until November, 1947, he was Chief Seismologist for the United Geophysical Company. Part of this time he also served as Vice-President and member of the Board of Directors.

Dr. Dix is the author of nine papers on geophysical and mathematical subjects in addition to unpublished research reports. His work has covered all fields of petroleum geophysics, but the principal emphasis has been on new field methods and new methods of interpretation of field data. A natural sideline of a thorough study of field methods and interpretative technique is research in instrument design, which he has followed for a number of years. He is a member of the American Mathematical Society, the American Physical Society, the Seismological Society of America, the American Geophysical Union, and the Society of Exploration Geophysicists.

CHARLES H. DRESBACH

CHARLES H. DRESBACH received the B.S. in Mining Engineering (Petroleum Geology Option) degree from the Missouri School of Mines in 1929; an M.S. in Petroleum Engineering from the University of Pittsburgh in 1933; and the professional E.M. degree from Missouri Mines in 1939. He has been with various subsidiaries of the Gulf Oil Corporation in both geological and geophysical capacities for a total of thirteen years, including the Gulf Production Company, Gulf Research and Development Company, Mexican Gulf Oil Company and Western Gulf Oil Company. From 1936 to 1941 he was at the Pittsburgh, Pa., office of the Gulf Research and Development Co. as supervisor of interpretation of the Gulf Coast section of seismograph exploration. During his location at the Pittsburgh office he was also on the faculty of the University of Pittsburgh as Visiting Lecturer in the Oil and Gas School and taught a graduate class in structural geology for two years of that time. From 1941 to 1947, he was assistant Chief Geologist and Supervisor of Geophysics for Western Gulf Oil Company, being located in the Los Angeles office. In March, 1947, he was transferred to the Colombian Gulf Oil Company as Chief Geologist and Assistant General Manager, headquarters in Bogota, Colombia. Pre-college graduation experience added about four years general engineering and oil field work.

He is a member of Sigma Gamma Epsilon, Triangle Fraternity, American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

JOHN SLOAT received the B.S. and M.S. degrees in electrical communications from the Massachusetts Institute of Technology in 1934. During 1932–33 he was employed by the Bell Laboratories of New York City where he helped develop a system for the measurement of the absolute values of sound pressures. In 1934 he was employed by the Western Geophysical Company, where he held in succession positions as driller, observer, computer, and party chief. In 1937 he became associated with the Union Oil Company of California in his present position where he is concerned with problems of geophysical interpretation and supervision. Mr. Sloat is a member of the Society of Exploration Geophysicists.

JOHN SLOAT

C. Y. FU

C. Y. FU received his B.S. degree in physics from the National Tsing Hua University, Peiping, China, in 1933. After one year of graduate study, he became assistant, and then instructor in physics in the same University. He was awarded a Chinese Government scholarship to go to Canada in 1940 and received his M.S. degree from McGill University in 1941. From 1941 to 1942, he was assistant in Geophysics at the Colorado School of Mines. He received his Ph.D. degree in Geophysics from the California Institute of Technology in 1944.

From 1944 to 1946, Dr. Fu was a research fellow in geophysics at the California Institute and at the same time did consulting work, first for the United Geophysical Company, and then for the Stanolind Oil and Gas Company. He was appointed Assistant Professor of Geophysics at the same Institute in 1946. In the summer of 1947, he resigned this post and returned to China to join the staff of the Institute of Meteorology to help develop a geophysical division of that Institute.

Dr. Fu is a member of Sigma Xi, the American Association for the Advancement of Science, the American Institute of Mining and Metallurgical Engineers, the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, the American Physical Society, the Seismological Society of America, and the American Meteorological Society, and is one of the founders of the Chinese Geophysical Society.

JOSEPH C. WATERMAN

JOSEPH C. WATERMAN was graduated with a Bachelor of Arts degree in Civil Engineering from Stanford University in 1924 and has been employed by Shell Oil Company, Incorporated, since that time in various phases of geophysical work—torsion balance, refraction shooting, reflection shooting, soil-gas analysis, and gravity work. Most of his work has been in California, although he spent one year in the Gulf Coast area and a short period in Alberta, Canada. He is a member of the Society of Exploration Geophysicists.

DEAN WALLING received the degree of A.B. in Mathematics with honors from Abilene Christian College in 1930. He spent most of the year 1929 with the Geophysical Research Corporation and was subsequently affiliated with the Geophysical Service, incorporated, from 1930 to 1933. Since 1933, Mr. Walling has been associated with Western Geophysical Company, of which company he is now the Executive Vice President. He is a charter member of the Society of Exploration Geophysicists.

THE SOCIETY ROUND TABLE

STANDING COMMITTEES FOR THE YEAR 1947–48

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B. G. Swan, Continental Oil Co., Ponca City, Okla.

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B. H. Treybig, Jr., The Texas Co.

Shreveport

George E. Wagoner, Chairman, The Carter Oil Co., Drawer 1739, Shreveport, Louisiana
H. M. Buchner, The Carter Oil Co.
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Ewin D. Gaby, Geophysical Service, Inc., Jackson, Miss.
Booth B. Strange, Western Geophysical Co., Natchez, Miss.
J. H. Todd, The California Company, Brookhaven, Miss.

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Gerald Burton, Shell Oil Company
M. D. Tucker, Stanolind Oil & Gas Company
M. J. Walczak, Atlantic Refining Company

Eastern States

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O. F. Ritzmann, The Gulf Companies
Milton Dobrin

Canada

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Arthur A. Brant, Toronto University, Toronto
J. H. Hodgson, Toronto University, Toronto
Hans Lundberg, Consulting Engineer, Toronto
J. T. Randell, Geo-Technical Development Co., Ltd., Toronto

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L. F. Athy, Continental Oil Co., Ponca City
A. B. Bryan, Carter Oil Co., Tulsa
Kenneth Burg, Geophysical Service, Inc., Dallas
E. D. Alcock, National Geophysical Co., Dallas
Dave P. Carlton, Humble Oil & Refining Co., Houston
O. C. Clifford, Atlantic Refining Co., Dallas
Ira Cram, Pure Oil Co., Chicago
E. L. DeGolyer, DeGolyer & MacNaughton, Dallas
C. Hewitt Dix, United Geophysical Co., Pasadena
Milton Dobrin, Naval Ordnance Laboratory, Washington
J. Brian Eby, Consulting Geologist, Houston
Frank Goldstone, Shell Oil Co., Houston

H. J. Hintze, Phillips Petroleum Co., Bartlesville
W. E. Hollingsworth, Sun Oil Co., Beaumont
J. W. Hoover, The California Co., New Orleans
J. C. Karcher, Continental Bldg., Dallas
Joseph A. Sharpe, C. H. Frost Gravimetric Surveys, Tulsa
Henry Salvatori, Western Geophysical Co., Los Angeles
Louis A. Scholl, The Texas Co., Houston
L. O. Seaman, Sinclair Prairie Oil Co., Tulsa
D. C. Skeels, Standard Oil Co., of N. J., New York
L. H. Waterfall, Union Oil Co. of California, Los Angeles
B. B. Weatherby, Geophysical Research Corp., Tulsa
Paul Weaver, Gulf Oil Corp., Houston
G. H. Westby, Seismograph Service Corp., Tulsa

Constitution and By-Laws

Wm. M. Rust, Jr., *Chairman*, Humble Oil & Refining Co., Houston
J. J. Jakosky, Union Oil Co., Los Angeles
G. E. Wagoner, Carter Oil Co., Shreveport
L. L. Nettleton, Gravity Meter Exploration Co., Houston
Henry C. Cortes, Magnolia Petroleum Co., Dallas
Cecil H. Green, Geophysical Service, Inc., Dallas
J. F. Gallie, Cabot Corp., Pampa, Tex.

Special Reviews

R. A. Geyer, *Chairman*, Humble Oil & Refining Co., Houston
Florence Robertson, St. Louis University, St. Louis
C. Hewitt Dix, United Geophysical Co., Pasadena
Milton B. Dobrin, Columbia Univ., New York
Noyes D. Smith, Shell Explor. & Prod. Lab., Houston
Henry R. Joesting, U. S. Geological Survey, Washington

Student Membership

James C.Menefee, *Chairman*, Magnolia Petroleum Co., Dallas
Ralph S. Jackson, Independent Exploration Co., Houston
Darrell S. Hughes, University of Texas, Austin
S. A. Lynch, Texas A. and M. College, Bryan
C. Hewitt Dix, United Geophysical Co., Pasadena
John H. Hodgson, University of Toronto, Toronto
V. L. Jones, University of Tulsa, Tulsa
Ralph C. Holmer, Colorado School of Mines, Golden

Best Paper Award

Roland F. Beers, *Chairman*, Geotechnical Corp., Dallas
W. T. Born, Geophysical Research Corp., Tulsa
Frank Goldstone, Shell Oil Co., Inc., Houston
M. King Hubbert, Shell Oil Co., Inc., Houston
Frederick E. Romberg, La Coste & Romberg, Austin
Paul Weaver, Gulf Oil Corp., Houston

Geophysical Education

James B. Macelwane, S. J., *Chairman*, St. Louis University, St. Louis, Mo.
Perry Byerly, University of California, Berkeley

Maurice Ewing, Columbia University, New York
Beno Gutenberg, California Institute of Technology, Pasadena
C. A. Heiland, Heiland Research Corp., Denver
M. King Hubbert, Shell Oil Co., Inc. Houston
D. C. Skeels, Standard Oil Co. of New Jersey, New York

Public Relations and Publicity

G. E. Wagoner, *Chairman*, Carter Oil Co., Shreveport
M. R. Budd, Hercules Powder Co., Wilmington, Del.
C. C. Campbell, Society of Exploration Geophysicists, Tulsa

Annual Survey of Geophysical Activity

E. A. Eckhardt, *Chairman*, Gulf Research & Development Co., Pittsburgh

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the President within thirty days. (Names of references are placed beneath the name of each nominee.)

ACTIVE

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H. M. Houghton, Andrew Gilmour, Arland I. Innes
Albert Lorenzo Ballou Jr.
R. W. Mossman, C. E. McClure, H. M. Thralls
Warren Randall Barnum
Sigmund Hammer, T. J. O'Donnell, E. A. Eckhardt
Robert Ray Bartel
B. J. Sorrells, E. D. Alock, K. H. Waters
Charles R. O. Bartlett
Oscar Weiss, J. H. Jones, Article III, Section 2 of Bylaws
Michael Isaag Behr
Oscar Weiss, J. H. Jones, Article III, Section 2 of Bylaws
Sanford David Blattner
Wesley H. Seifert, Paul E. Nash, Jack C. Pollard
Stanley Bolanovich
H. E. Shell, C. E. Reel, F. Ittner
Richard Brewer
E. L. DeLoach, O. C. Clifford, Jr , A. E. McKay
Robert Blakemore Briggs Jr.
J. F. Freel, H. G. Patrick, D. P. Carlton
Robert A. Broding
J. P. Minton, D. H. Clewell, C. F. Rust
Elton Bryan Claunch
W. H. Morgan, C. R. Lowe, R. S. Jackson
Edward Jolley Combs
C. B. Bazzoni, W. W. Hollingsworth, L. G. Ellis.
William D. Cortright
Deal Walling, John Sloat, T. P. Ellsworth

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Robert Dyk
John Sloat, C. H. Johnson, N. R. Shade
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Guy Wesley Fisher
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John V. Franklin
A. E. McKay, O. C. Clifford, Jr., C. H. Hightower
Robert Louis Frossard
G. H. Westby, A. J. Barthelmes, Robert Baum
Robert Taylor Gallagher
W. B. Agocs, Section 2 of Article III in the Bylaws
Malcolm Hobson Green
Oscar Weiss, J. H. Jones, Article III, Section 2 of the Bylaws
Jack Francis Harang
W. J. Osterhoudt, John E. McGee, G. B. Lamb
Robert Lee Henson
W. E. Hollingsworth, A. Winterhalter, J. W. Millington
Harold Kingsley Herr
D. J. Wolff, G. D. Kendall, Albert Taylor
Gerhard Herzog
Alexander Wolf, L A. Scholl Jr., J. C. LeGrand
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P. J. Rudolph, T. L. Allen, W. Lee Moore
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Don Winter Jopling
Eugene McDermott, E. J Stulken, C. H. Green
Foster Gordon Kirby
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H. C. Kriegel
G. P. Montgomery, A. G. Starr, G. L. Jackson
Leonard Joseph Larguier
T. A. Manhart, A. J. Barthelmes, H. M. Thralls
William Palmer Lawrence
Arland I. Innes, John L. Ferguson, Paul H. Jeffers
Robert Greenleaf Mills
K. A. Robertson, N. J. Christie, J. C. Hoffman

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George Augustat, S. W. Totten, J. A. Harris

Sherman Rex Spivey
J. Frank Rollins, Walter D. Baird, C. H. Green
Verne David Viterbo Jr.
T. L. Allen, P. J. Rudolph, W. L. Homan
Kia-Kang Wang
Chalmer J. Roy, P. A. Bloomer Jr., Ramond E. Halsey

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Victor J. Blum, S. J.
Clarence William Bowlby
Ralph C. Holmer
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Darrell S. Hughes
William Douglas Edward Cardwell
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Ruth Breedlove
B. de Blank
Ralph C. Holmer
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TRANSFER TO ASSOCIATE MEMBERSHIP

David Coolbaugh
William W. Davis

RE-INSTATEMENT TO ACTIVE MEMBERSHIP

Harris Cox
Robert L. Suggs
B. G. Hubner, Jr.

REPORT ON ORGANIZATION OF THE ARK-LA-TEX GEOPHYSICAL SOCIETY

The immense oil and gas producing region consisting of the areas of southern Arkansas, north Louisiana, and a portion of northeast Texas has become popularly known as the Ark-La-Tex area. Many oil companies and businesses associated with the petroleum industry have their home or district offices in the key and centrally located city of Shreveport. Among the thousands of men employed in the petroleum industry in the Ark-La-Tex area are scores of geologists and geophysicists.

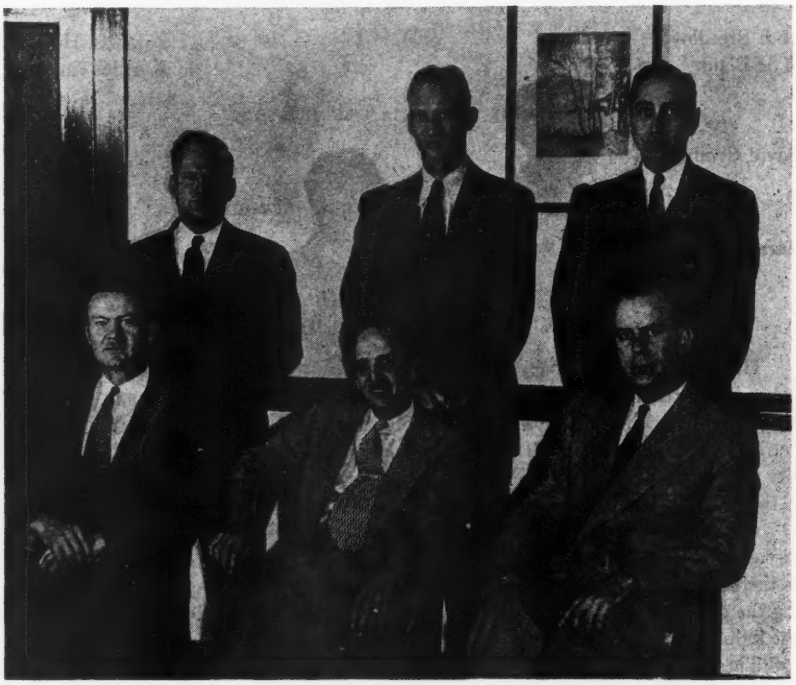
During the course of the past two years, there have been private and informal discussions among these men at various places such as street corners, lunch rooms, and in their own offices while looking across a stack of seismograms, well logs, etc., concerning the desirability of an organization or society representing the geophysical phase of the industry.

These discussions bore fruit in that they culminated in the calling of a luncheon meeting in June at Monsour's Restaurant in Shreveport, for all those in the Ark-La-Tex area interested in geophysics. This first, or "feeler" meeting as it might be designated, was called for the purpose of feeling out the opinions of those present on the feasibility of a geophysical society and what they wanted for its objective and was a success. After being called to order by Mr. L. F. Fischer, the meeting was turned over to Mr. R. M. (Dick) Wilson who called on those in attendance to discuss the formation of a society. Quite a number of the forty-six men present expressed their opinions and pledged their support of such a society. A motion was made and voted authorizing Mr. Wilson to appoint an organizing committee. This committee was composed of

L. F. Fischer, Sohio Petroleum Company; H. M. Buchner, Carter Oil Company; and Carl L. Bryan, Gulf Refining Company.

After the first meeting, questionaires were sent out to interested parties in order to collect information on further organization of the society. It was the concensus of opinion that the society should have as its objective to promote the science of geophysics especially as it applies to exploration and to promote fellowship and cooperation among those interested in geophysical problems. The feeling among interested parties as a whole was that cooperation and coordination is of utmost importance to the geologist and geophysicist in their efforts toward the discovery of oil and gas reserves. It has been said that after all, in their search for the solution to some of the more complex and disturbing problems, the picture might turn up in the form of an image of a confused fellow geologist or geophysicist gazing into the opposite sides of the same crystal ball.

The second meeting was held at a luncheon on September 30, 1947, at the same place as the first meeting. With L. F. Fischer acting as chairman, several names for the society were discussed and an official vote gave it the name of The Ark-La-Tex Geophysical Society. Nominations were made and first officers were elected. George E. Wagoner, Director of Explorations for the southern division of the Carter Oil Com-



Standing left to right, L. F. Fischer, Geophysicist for Sohio Oil Company, chairman of organizing committee; Carl L. Bryan, district geophysicist for Gulf Refining Company, organizing committee; Harry M. Buchner, coordinating geologist for Carter Oil Company, secretary of organizing committee. Seated left to right: George E. Wagoner, director of explorations for the southern division of Carter Oil Company, president; R. M. (Dick) Wilson, geologist for Ohio Oil Company, vice-president; J. Ryan Walker, head of geophysical department of Arkansas Fuel Oil Company, secretary-treasurer.

pany, was named president; R. M. (Dick) Wilson, Geologist with Ohio Oil Company, and a past president of the Shreveport Geological Society, was made vice-president; and J. R. Walker, Head of the Geophysical Department of Arkansas Fuel Oil Company, was elected secretary-treasurer. Wagoner appointed as a constitutional committee to draw up a constitution and by-laws, L. F. Fischer, H. M. Buchner, Carl L. Bryan, and Carl Howard. With the exception of Howard, who is with the Union Producing Company, all were on the temporary organizing committee appointed in June.

Officers of the society are elected for the period of one year. Elections will be held at the society's annual meeting in May. Anyone in the Ark-La-Tex area interested in geophysics is eligible for membership. The membership dues are two dollars annually.

Since the society was organized on September 30, 1947, two other meetings have been held. One of these meetings was for the final approval of the constitution and by-laws.

It is the plan of the society to hold one meeting (generally luncheon meetings) during the first week of each month. Technical papers will be read and talks will be made by local or outside parties, or interesting films will be shown at these meetings.

The Ark-La-Tex Geophysical Society extends an invitation to members of other such societies in various sections of the country to attend their meetings whenever it is possible for them to do so.

J. R. WALKER, *Secretary-Treasurer*

THE ORGANIZATION OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS HOUSTON SECTION

On November 20, 1947, about 100 geophysicists met at 4:00 P.M. at the Houston Engineers Club, 2615 Fannin Street to organize the Houston Section of the Society of Exploration Geophysicists. At an earlier meeting on October 7, Dr. Wm. M. Rust had been appointed Chairman of the Constitution Committee, Dr. E. E. Rosaire had been appointed Chairman of the Nominating Committee, and W. J. Osterhoudt was made temporary chairman to organize the new section.

After calling the meeting to order, Dr. L. W. Blau read the proposed constitution. The constitution was accepted by unanimous vote. Dr. E. E. Rosaire read the list of nominations for officers, there being two candidates named for each office. The following men were elected:

President	—W. J. Osterhoudt, Gulf Research & Development Co.
First Vice President	—W. D. Mounce, Humble Oil & Refining Company.
Second Vice President	—Roy L. Lay, The Texas Company.
Secretary	—C. C. Zimmerman, Keystone Exploration Company.
Treasurer	—Ed. S. Shearer, Tide Water Associated Oil Co.

On November 28 and 29, the Society of Exploration Geophysicists joined the Houston Meeting of the American Physical Society to hold two joint sessions under Dr. L. L. Nettleton and Dr. Dean L. DuBridge as chairmen. On Friday evening, November 28, several geophysicists attended the American Physical Society Dinner and heard Dr. A. H. Compton speak on "The Physicists' Role in International Relations."

At a meeting of the Executive Committee of the Houston Section on December 2, the officers and chairmen of the Nominating Committee and the Constitution Com-

mittee drew up a formal petition to submit to the Council of the Society of Exploration Geophysicists requesting recognition of the local section.

Due to the unusually full schedule of technical meetings at Houston in December 1947, the Executive Committee voted to hold the first technical meeting of the Houston Section in January 1948. The exact date will be announced later.

W. J. OSTERHOUDT, *President*

ORGANIZATION OF DALLAS GEOPHYSICAL SOCIETY

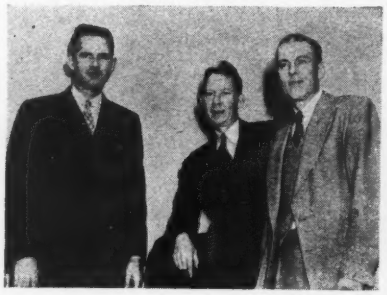
The Dallas Geophysical Society was organized on October 1st at a meeting at tended by a large group of geophysicists and others interested in geophysics. Mr. A. E. McKay was acting Chairman, and Mr. W. W. Newton acting Secretary-Treasurer. A committee to draft a Constitution and By-Laws was appointed. This committee consisted of Mr. W. W. Newton, The Geotechnical Corporation, Chairman; Mr. K. E. Burg, Geophysical Service, Inc.; Mr. Paul E. Nash, Magnolia Petroleum Company; and Mr. A. E. McKay, Atlantic Refining Company.

The first regular monthly meeting was held November 4th at Fondren Library

Organization meeting of the Dallas Geophysical Society, November 4, 1947.

Auditorium on the Southern Methodist University campus, with an attendance of eighty-eight.

The Constitution and By-Laws were adopted and charter members were signed. Permanent officers for the coming year were elected from a slate prepared by Messrs. Henry C. Cortes and Cecil H. Green, Past President and President, respectively, of



Officers of the Dallas Geophysical Society, left to right; W. W. "Ike" Newton, First Vice-President; A. E. "Sandy" McKay, President; D. Ray Dobyns, Secretary-Treasurer. Absent, Chester J. Donnally, Second Vice-President.

S.E.G. President Cecil H. Green, left; and Past S.E.G. President Henry C. Cortes (1945–1946), members of the Dallas Geophysical Society.

the Society of Exploration Geophysicists. Mr. A. E. McKay of Atlantic Refining Company was elected President; Mr. W. W. Newton of Geotechnical Corporation, 1st Vice-President; Mr. C. J. Donnally of Western Geophysical Company, 2nd Vice-President; and D. R. Dobyns of the Magnolia Petroleum Company, Secretary-Treasurer.

Following the business session Mr. Paul E. Nash presented a paper on "A Resume of Efforts to Promulgate Rules and Regulations governing Offshore Seismic Exploration on the Texas Gulf Coast." Mr. Kenneth Burg presented a paper on "Seismic Operations and Offshore Operations on the California Coast."

Meetings are to be held monthly and the membership is open to all persons interested in the science of geophysics, including students.

The Dallas Geophysical Society will petition for affiliation as a local section of the Society of Exploration Geophysicists.

D. R. DOBYNS, *Secretary-Treasurer*

PACIFIC COAST MEETING

In conjunction with the Pacific Section of American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, the Pacific Coast members of Society of Exploration Geophysicists held their annual meeting at the Huntington Hotel in Pasadena, California on Thursday and Friday, November 6th and 7th, 1947.

The Thursday morning session was opened by Herbert Hoover, Jr., who invited all to enjoy the hospitality of Pasadena and its many places of interest. Greetings of the National S. E. G. officers were extended by Cecil H. Green, National President, who discussed the many accomplishments of the past year and the extensive plans for the future. Of particular interest was the news of progress in the formation of new sections in Tulsa, Dallas, Houston and Shreveport. The marked increase in membership, the formation of new sections and the growth of the case histories volume, all testify to the healthy condition of the Society.

The popularity of last year's symposium on Multiple Reflections prompted the scheduling this year of a symposium on Correlation in California. The lead paper was presented by John Sloat, who combined very successfully in one paper the qualities of technical excellence and a high degree of audience interest. This interest was sustained in the following papers on particular aspects of the correlation problem:

Significance of the "A" Reflection of Fresno and Madera Counties, California, by Loring V. Snedden

Complications in Basement Reflection Correlation, by W. D. Cortright

Correlation Possibilities in the Sacramento Valley, by Kenneth S. Cohick

Examples of Seismic Sections Across Known Faults, by O. F. Van Beveren and M. G. Smith.

Strategic Correlation vs. Multiple Reflections, by Cecil E. Reel.

From 2 P.M. to 5 P.M., following a joint luncheon with the other societies, Curtis Johnson and Joseph C. Waterman presided over the afternoon technical session which included the following papers:

Notes on the Migration of Steep Dips with Special Reference to Curved Paths by E. J. Handley

Correlation of Reflections with Electrical and Geological Logs, by C. Hewitt Dix

Geophysical History of the Wilmington Oil Field, Los Angeles Basin California, by N. R. Shade

Case History of McDonald Island, Phil P. Gaby and A. J. Solari.

On the Penetration of Alternating Electrical Currents into the Ground, by G. Potapenko.

An improved Method of Land Surveying for Use in Brush Covered Areas, by Kenneth H. Waters.

Well Velocity Shooting in California, by Robert J. Wells.

Note on Shooting in a Well to Determine Velocity, by Robert Dyk.

Three Dimensional Control and Calculations in Seismic Dip Work, by E. J. Handley.

The final S. E. G. session was in the form of a luncheon meeting on Friday in the Mirror Room of the Huntington Hotel. Milton C. Born presided, and the speaker was Cecil H. Green, President of S. E. G., who described the formation of the Geophysical Society of Tulsa. Discussion following Mr. Green's talk resulted in the decision among those present to organize formally a Pacific Coast Section of the Society of Exploration Geophysicists.

THE HOUSTON MEETING OF THE AMERICAN PHYSICAL SOCIETY AND THE SOCIETY OF EXPLORATION GEOPHYSICISTS

The meeting on November 28th and 29th in Houston of The American Physical Society was the first meeting in Texas of that Society. As a fitting introduction to Texas, the Society of Exploration Geophysicists collaborated in arranging a one-half day symposium on "Underground Applications of Physics," as follows:

Field Equations of the Flow of Liquids through Porous Solids. M. King Hubbert, Shell Oil Company.

Seismic Travel Paths at Bikini Atoll. R. F. Beers, Geotechnical Corporation.

Physical-Chemical Interpretation of a Geological Problem: Rocks from Sea Water. Paul Weaver, Gulf Oil Corporation.

Industrial Applications of Radioactivity. Gerhard Herzog, Texas Company.

This symposium was held on Saturday morning. In addition, part of the Friday afternoon session was given to geophysical papers and included the following:

Microseisms and Hurricanes. Beno Gutenberg, California Institute of Technology.

Seismic Measurements in the Antarctic. T. C. Poulter, Armour Research Foundation.

The sessions were well attended both by members of the Society of Exploration Geophysicists in the Houston area and many visiting members of the American Physical Society. The geophysical papers were well received and seemed to be of particular interest to the members of the Physical Society to whom much of this material was quite new.

S.E.G. sessions were held in the Physics Ampitheater of Rice Institute, with Dr. L. L. Nettleton, General Program Chairman for S.E.G. in charge of arrangements for the Society's portion of the program.

ANNOUNCEMENTS

1948 ANNUAL MEETING

As previously announced (GEOPHYSICS, October, 1947, page 700) the 1948 annual meeting of the S.E.G. will be held in Denver, Colorado on April 26–29.

The plans for the meeting are now quite definitely formulated and the program for the week will be as follows:

Sunday, April 25—Arrival of special trains from Texas and possibly from Oklahoma.

Monday, April 26—A.A.P.G. committee meetings. S.E.G. technical papers. Evening, A.A.P.G. Research Committee.

Tuesday, April 27—Morning, Joint Session including presidential addresses, etc. Afternoon, general papers including a review of geophysics.

Wednesday, April 28—A.A.P.G. technical papers. S.E.G. technical papers and Mining Symposium, possibly running into the evening.

Thursday, April 29—A.A.P.G. technical papers. S.E.G. local field trip. Evening, dinner dance.

Friday, April 30 and Saturday, May 1—A.A.P.G. field trips.

Authors of papers to be presented at the 1948 meeting are urged to have titles and abstracts of their papers in the hands of Dr. C. A. Heiland, Department of Geophysics, Colorado School of Mines, Golden, Colorado by March 1, 1948.

Complete instructions concerning hotel reservations and program details will be mailed to all S.E.G. members in ample time for arranging reservations.

S.E.G. REGULATIONS REGARDING THE RELEASE OF TECHNICAL PAPERS TO TRADE JOURNALS

Upon proper application, the Business Manager may allow advance reproduction of "Titles and Abstracts for any and all Papers Comprising the Program for an Annual, Regional or Local Section Meeting," provided that due acknowledgment is given.

Papers accepted for publication in GEOPHYSICS are the property of the Society. Members desiring prior publication of such papers in trade journals, or elsewhere than in GEOPHYSICS, should submit to the Business Manager one complete copy of the paper and the illustrations, together with the name of the periodical in which publication is desired. Papers printed in trade journals or elsewhere without having been submitted to the Business Manager are not eligible for publication in GEOPHYSICS.

Upon receipt of such request, the Business Manager will forward the copy of the paper in question to the Editor for examination. Release may be obtained upon joint approval of Editor and Business Manager, subject to acknowledgment to the Society and mention of the particular S.E.G. meeting where the paper was first presented.

Papers which have already appeared in GEOPHYSICS may be released by the Business Manager, subject to acknowledgment of GEOPHYSICS.

Popular versions of technical papers by Trade Journal Editorial Staffs may be permitted before publication in GEOPHYSICS by permission of original author (or authors) and Business Manager, subject to acknowledgment of the Society and mention of the first S.E.G. Meeting where original paper was presented.

EXPANSION OF THE BUSINESS OFFICE

The Business Office of the Society was moved on September 1, 1947 from 213 Ritz Building to 817 South Boulder, Rooms 209 and 210, Tulsa, Oklahoma. The mailing address, however, remains *Box 1614, Tulsa 1, Oklahoma.*

This move was made on the recommendation of a special committee, headed by Secretary-Treasurer T. A. Manhart and including Joseph A. Sharpe and George E. Wagoner, who were appointed by President Green to investigate the need for expansion of the Business Office.

The improvements recommended and now completed include increasing the amount of office space from one room to two rooms, purchasing several items of essential equipment and finally, employing Mrs. Gloria Highfield as full-time secretary to the Business Manager.

Members of the Society are cordially invited to visit the Business Office whenever they are in Tulsa.

MANUSCRIPT TRANSLATIONS FROM THE RUSSIAN

All geologic publications.—The Committee on Russian Literature of the Geological Society of America has begun the compilation of a list of translations from Russian into English of geologic papers and books; that is, a list of translations extant in manuscript form in the United States. Please send information as to any such translations to the committee chairman or to Geological Society headquarters. The word *geologic* is used here in its widest sense to extend inclusively from geophysics to paleontology.

Current geologic publications.—If information about translations of recent publica-

tions is received soon enough, it will be included in forthcoming volumes of the *Bibliography and Index of Geology Exclusive of North America* and the *Bibliography of Economic Geology*, subject to permission from proprietors of translations.

RONALD K. DEFORD, *Chairman*
Box 1814, Midland, Texas

PUBLICATION OF THE GEOPHYSICAL ABSTRACTS

The United States Geological Survey has resumed publication of the Geophysical Abstracts after a 4-year interval, during which they were issued by the U. S. Bureau of Mines.

The Geophysical Abstracts are published quarterly as an aid to those engaged in geophysical research and exploration. The bulletin covers world literature on geophysics contained in periodicals, books, and patents. It deals with exploration by gravitational, magnetic, seismic, electrical, radioactive, geothermal, and geochemical methods and with underlying geophysical theory and related subjects.

Copies may be purchased singly or by annual subscription from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. For subscription, the Superintendent of Documents will accept a deposit of $5.00 in payment for subsequent issues. When this fund is near depletion the subscriber will be notified. The deposit may also be used to cover purchase of any other publication from the Superintendent of Documents.

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912, AS AMENDED BY THE ACTS OF MARCH 3, 1933, AND JULY 2, 1933

of GEOPHYSICS, published quarterly at Menasha, Wisconsin, for January, 1948

State of Oklahoma } ss.
County of Tulsa }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Colin C. Campbell, who, having been duly sworn according to law, deposes and says that he is the business manager of GEOPHYSICS, and that the following is, to the best of his knowledge and belief, a true statement of ownership, management (and if a daily, weekly, semiweekly or triweekly newspaper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the act of August 24, 1912 as amended by the acts of March 3, 1933, and July 2, 1946 (section 537, Postal Laws and Regulations), printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, Society of Exploration Geophysicists, P. O. Box 1614, Tulsa 1, Oklahoma; Editor, Dr. M. King Hubbert, P. O. Box 2099, Houston 1, Texas; Managing Editor, Dr. M. King Hubbert, P. O. Box 2099, Houston 1, Texas; Business Manager, Colin C. Campbell, P. O. Box 1614, Tulsa 1, Oklahoma.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.) Society of Exploration Geophysicists, P. O. Box 1614, Tulsa 1, Oklahoma; Cecil H. Green, President, 6000 Lemmon Ave., Dallas, Texas; Dr. L. L. Nettleton, Vice-President, 1348 Esperson Bldg., Houston, Texas; Dr. J. J. Jakosky, Past-President, 1063 Gayley Ave., Los Angeles, Calif.; T. A. Manhart, Secretary-Treasurer, P. O. Box 1590, Tulsa 1, Oklahoma.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given: also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is not required. (This information is required from daily, weekly, semiweekly, and triweekly newspapers only.)

COLIN C. CAMPBELL (Signed)

Sworn to and subscribed before me this 4th day of November, 1947.
[SEAL] HARRY A EICHENBERGER (Signed)

(My commission expires Aug. 12, 1951.

PERSONAL ITEMS

(Members are requested to forward material for inclusion in Personal Items to C. C. Campbell, P.O. Box 1614, Tulsa, Oklahoma)

THE UNIVERSITY OF TULSA STUDENT GEOPHYSICAL SOCIETY

Geophysics students at the University of Tulsa have petitioned for affiliation as a Student Section of the Society of Exploration Geophysicists. First row, left to right: V. L. Jones, Faculty Sponsor; Bobby G. Preston, Leah Plumlee, Duncan M. Bowie, Treasurer; Ross E. Brannian, Secretary; William W. Crump, Vice President; Chet H. Jameson, Jr., President. Second row: W. D. Cardwell, E. W. Racek, Gordon E. Lyons, Schley J. Babin, Jack M. Crudup, Robert J. Gilmore, Third row: Charles A. Schad, Donald N. Mooney, Tom Strayhorn, Leland E. Moore, Sam C. Cooke, William J. Cunningham, David F. Jewell, William J. Robinson. Back row: Charles E. Jones and Nelson H. Williamson.

E. D. LYNTON, Oil Consultant for the Institut du Petrole, Paris, France, has been decorated by the Sultan of Morocco with the order of "Commander of Ouissam Alaouite" for his work there in 1943 and 1944. This is an honor seldom conferred upon Americans.

W. R. MITCHELL, Vice President in Charge of Services for the National Geophysical Company, Inc., spoke before the senior Electrical Engineering students at Kansas State College on Thursday, November 13, 1947. Mr. Mitchell's talk concerned opportunities for electrical engineers in the petroleum industry.

RAY K. CARTER has joined Advanced Exploration Company after serving five years in the Naval Air Transport Service Mid-Pacific Area in the rank of Lieutenant Commander. Before being called to active duty Mr. Carter was with Geophysical Service Inc.

OLAF F. SUNDT, Petroleum Attache in the Foreign Service of the United States, has been transferred from Lima, Peru to Paris, France where his address will be the American Embassy.

H. V. W. DONOHOO, after completing a course of study at Columbia University, is now with the School of Mineral Industries, University of Utah, Salt Lake City 1, Utah.

LOUIS B. SLICHTER, formerly with the Department of Geology, University of Wisconsin, is now with the Institute of Geophysics, University of California, Los Angeles 24, California.

A. C. YOKUBAITIS recently resigned his position as Geophysicist with American Exploration Company, Lafayette, Louisiana to accept a position of Geophysicist in the Exploration Department of The Pan American Production Company, Houston, Texas. He may be addressed in care of the company at 1248 Mellie Esperson Building, Houston 2, Texas.

CHALMER J. ROY has transferred from the Department of Geology, Louisiana State University, to the Department of Geology, Iowa State College, Ames, Iowa.

MEMBERS OF THE GEOPHYSICAL SOCIETY OF TULSA have enjoyed three successful meetings during the Fall of 1947. Dr. E. M. McNatt of Carter Oil Company spoke at the first meeting held October 16 on the design and operation of an integrating gradiometer. Rev. James B. Macelwane, S.J., Dean of the Institute of Geophysical Technology of St. Louis University, discussed microseismic ground motion at the November 13th meeting. E. J. Handley of Century Geophysical Corporation also reported on the S.E.G. Pacific Coast Meeting. Guest speaker at the December 11th meeting was John H. Hidy, Chief Development Engineer of the Frost Geophysical Corporation. Mr. Hidy spoke on airborne magnetic instruments. All meetings were held informally in the Student Union lounge at The University of Tulsa.

THE NATIONAL GEOPHYSICAL COMPANY, INC., announces the removal of its executive and accounting offices from the Tower Petroleum Building to 8800 Lemmon Avenue, Dallas, Texas. The new location will house the company's main offices, laboratory, research department and drill shop.

EDWARD C. BERTOLET advises of a change in his address from Box 2508, Los Angeles, to 6214 Bluebell Avenue, North Hollywood, California.

A. J. ODEN, seismic party chief for Magnolia Petroleum Company, is now located at Box 421, Aztec, New Mexico.

FRED A. BENDER, formerly in the Geophysics Department at the University of Pittsburgh, has moved to Golden, Colorado, where his address is 1301 Maple Street, No. 18.

N. H. BANTA, formerly with the Independent Exploration Company, has accepted the position of seismic supervisor with the Iraq Petroleum Company and may be addressed in care of that company, Tripoli, Lebanon.

E. W. WESTRICK has moved from Oakmont, Pennsylvania to 203 Bay Street, Toronto 1, Ontario, the address of his employer, Dominion Gulf Company.

DE WITT C. VAN SICLEN is now with Drilling and Exploration Company, Inc., 158½ Cypress Street, Abilene, Texas.

R. L. KRETZ has moved from Laramie, Wyoming to 3120 Carmen Drive, Wichita, Kansas.

R. C. DUNLAP, JR., District Supervisor for Geophysical Service, Inc., has moved his offices to 126 George Hay Building, Bakersfield, California.

PAUL D. BALBIN, formerly Division Seismograph Supervisor in the Fort Worth office of Stanolind Oil and Gas Company, is now Geophysical Supervisor in the company's General Offices at Tulsa, Oklahoma.

CHARLES C. BATES, consultant and partner in Bates and Glenn, Meteorological Engineers at 906 Washington Blvd., Washington 19, D. C., has recently been appointed a member of the Panel on Geographic Environment, Research and Development Board, Department of National Defense.

JOE R. BRADLEY, JR. has resigned his position as interpreter with Stanolind Oil and Gas Company to join the Texas Seismograph Company as party chief. His address is P.O. Box 2069, Wichita Falls, Texas.

NEAL CLAYTON, Seismologist with Republic Exploration Company is now in the Tulsa Office of the company and may be addressed at Box 2208, Tulsa, Oklahoma.

LEWIS C. CRIDER resigned from the employ of The California Company in August of 1947 and has been doing surface geological mapping for Stanolind Oil and Gas Company since September. His address is P.O. Box 1680, Wichita Falls, Texas.

MILTON B. DOBRIN, Physicist with the Naval Ordnance Laboratory, will be on leave during the spring semester at Columbia University where he will act as co-organizer and co-teacher with Dr. Maurice Ewing of a course in "Prospecting Geophysics for Petroleum Geologists and Mining Engineers."

O. K. FULLER, JR., party chief with United Geophysical Company, is now located in Pakistan. His mailing address remains 2655 Las Lunas, Pasadena 8, California.

ROBERT L. GEYER, formerly a seismologist with Seismograph Service Corporation in Caracas, Venezuela, has received an appointment as an Instructor in the School of Geology at Louisiana State University and will begin his duties there February 6, 1948.

A. G. HARVEY has resigned from Geophysical Service Inc., to accept the position of party chief with Delta Exploration Inc., 1537 Fern St., New Orleans, Louisiana.

H. E. HAWKES, JR., Geologist with U. S. Geological Survey in Washington, is now working on the development of geochemical methods of prospecting for ore deposits.

WALTER E. HEINRICHS, JR. resigned his position as Geophysicist for the Bureau of Reclamation in July 1947 to join the staff of the Newmont Mining Corporation. His permanent address is 509 21st Street, Golden, Colorado.

H. M. HORTON, Chief Geologist for The Superior Oil Company of Venezuela, Apartado 48, Caracas, rejoined the company on September 1, 1947 after eight years absence in independent work in Illinois and the Pacific Coast.

RECOMMENDED AMENDMENTS TO THE CONSTITUTION AND BYLAWS

REPORT OF THE CONSTITUTION AND BYLAWS COMMITTEE

The Constitution and Bylaws Committee of the Society of Exploration Geophysicists held a meeting in Houston on January 9, 1948 to consider the various objections raised to various provisions in the revised Constitution. While all revisions were approved by a large majority, the objections raised by a small minority appeared to the Committee to be so carefully considered that the Committee is of the opinion that amendments meeting these objections should be submitted to the membership of the Society.

The Committee respectfully submits the following list of amendments for consideration by the Council of the Society of Exploration Geophysicists at the annual meeting in Denver in April 1948. This list of proposed amendments has been submitted by private mailing to all active members in order that they may be prepared to discuss them at the annual meeting of the Society in Denver.

AMENDMENTS

Amendment A. The membership class of Fellow is to be abolished and all references in the Constitution and Bylaws to Fellows shall be deleted. Any renumbering of sections necessitated by such deletion will be made.

Amendment B. Article III, Section 9, for the words "may not publish his affiliation with the Society," substitute the words "in publishing his affiliation with the Society shall clearly indicate his grade of membership."

Amendment C. Article IV, Section 1, delete Sections 1 and 2 and substitute therefor "Membership of any class shall be contingent upon conformance with the established principles of professional ethics." In Bylaws Article III, Section 3, delete second sentence and in Bylaws Article VI, Section 4, delete "shall be found guilty of a violation of the Code of Ethics of this Society, or."

Amendment D. Article VIII, Section 1, before the words "District Representatives" delete the word "the" and add "and all elected." Cancel "and the chairmen of all standing committees." Article VIII, Section 3, at the end add "All committee chairmen shall attend this meeting, but, as chairmen, shall have no vote."

Amendment E. Article XII, Section 1, at end add "Council may designate Districts outside the area of the continental United States."

Amendment F. Cancel Article XII, Section 2.

Amendment G. Renumber Article XII, Section 3 as Section 2 and before the words "one District Representative," insert the words "for each seventy-five Active Members of the Society, who are not members of a Local Section."

Amendment H. Amend Bylaws Article III, Section 5 by adding at the end "In the case of applicants for Student Membership, publication is not required. The Student Member shall be pronounced elected when approved by the Secretary-Treasurer."

Amendment I. Article IV, Section 3, delete the entire section. Renumber Sections 4 and 5, and in Section 2, after the word "Active" add the words "or Associate."

W. M. RUST, JR., *Chairman*